



Shaw Environmental, Inc.

312 Directors Drive
Knoxville, TN 37923
865.690.3211
Fax 865.690.3626

January 31, 2005

Commander
U.S. Army Engineer District, Nashville
ATTN: CELRN-EC-R-M (Mrs. Linda Ingram)
110 Ninth Avenue South, Room 682
U.S. Court House Annex
Nashville, Tennessee 37203

**Submittal of the Final Baseline Human Health Risk Assessment of Groundwater
Work Plan
For the Phase II Groundwater Remedial Investigation
Former Plum Brook Ordnance Works, Sandusky, Ohio
Contract Number DACA62-00-D-0002; Shaw Project Number 833886**

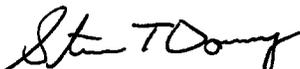
Dear Mrs. Ingram:

In accordance with the requirements of Delivery Order 0014 of Contract Number DACA62-00-D-002, Shaw is pleased to submit the Final Baseline Human Health Risk Assessment of Groundwater Work Plan for the Phase II Groundwater Remedial Investigation of the TNT and Red Water Pond Areas at the Former Plum Brook Ordnance Works located in Sandusky, Ohio.

Enclosed are six (6) copies of the final report. Copies have also been forwarded to recipients listed on the distribution list, quantities as indicated. Responses to Comments received on the November 30, 2004 Draft Work Plan are attached to this Final and have been incorporated into the text.

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

Sincerely,


Steven T. Downey, P.E.
Project Manager

Enclosures

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Mr. Ron Nabors Site Coordinator Division of Emergency and Remedial Response (DERR) Ohio Environmental Protection Agency 347 North Dunbridge Road Bowling Green, Ohio 43402-0466	10, 11
Ms. Laurie Moore Risk Assessment Coordinator Ohio EPA - Southwest District Office Office of Federal Facilities Oversight (OFFO) 401 E. Fifth Street Dayton, Ohio 45402	12
Mr. Robert Lallier Environmental Coordinator NASA - Plum Brook Station 6100 Columbus Avenue Sandusky, Ohio 44870	13, 14
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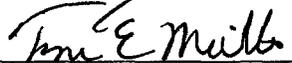
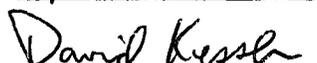
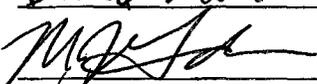
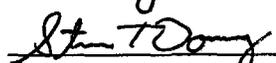
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Originator	<u>T. Siard</u>	<u>Risk Assessor</u>		<u>1-27-05</u>
Tech. Review	<u>T. Mattis</u>	<u>Risk Assessor</u>		<u>1/28/05</u>
Tech. Review	<u>D. Kessler</u>	<u>Geologist</u>		<u>1-27-05</u>
Tech. Review	<u>M. Gunderson</u>	<u>Geologist/Task Mgr</u>		<u>1-27-05</u>
Quality Assurance Mgr	<u>M. Hall</u>	<u>QA Manager</u>		<u>1-28-05</u>
Project Manager	<u>S. Downey</u>	<u>Project Manager</u>		<u>1-27-05</u>

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**Baseline Human Health Risk Assessment
of Groundwater Work Plan
Former Plum Brook Ordnance Works
Sandusky, Ohio**

**Prepared For:
U.S. Army Corps of Engineers**

**Prepared By:
Shaw Environmental, Inc.
312 Directors Drive
Knoxville, Tennessee 37923**

January 2005

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List of Acronyms

AOC	area of concern
AT	averaging time
BHHRA	baseline human health risk assessment
BSC	background screening concentration
BTEX	benzene, toluene, ethylbenzene, and xylenes
BW	body weight
cm ²	square centimeter
cm/hour	centimeter per hour
COC	chemicals of concern
COPC	chemicals of potential concern
CSEM	conceptual site exposure model
D&M	Dames & Moore
DA	dose absorbed per unit body surface area per event
°F	degrees Fahrenheit
DERP-FUDS	Defense Environmental Restoration Program – Formerly Used Defense Sites
DNT	dinitrotoluene
ED	exposure duration
EF	exposure frequency
EPA	U.S. Environmental Protection Agency
EPC	exposure-point concentration
ET	exposure time
GAF	gastrointestinal absorption factor
gpm	gallons per minute
GSA	General Services Administration
HHEM	human health evaluation manual
HI	hazard indices
HQ	hazard quotient
ILCR	incremental lifetime cancer risk
IRIS	Integrated Risk Information System
IT	IT Corporation
kg	kilogram
K _p	permeability coefficient
L/cm ³	liter per cubic centimeter

List of Acronyms (Continued)

L/day	liters per day
m ³	cubic meters
m ³ /hour	cubic meters per hour
MDC	maximum detected concentration
µg/L	micrograms per liter
mg/cm ² -event	milligrams per square centimeter per event
mg/L	milligrams per liter
mg/kg-day	milligrams per kilogram-day
mg/m ³	milligrams per cubic meter
NASA	National Aeronautics and Space Administration
OEPA	Ohio Environmental Protection Agency
PAH	polycyclic aromatic hydrocarbons
PBOW	Plum Brook Ordnance Works
PRG	preliminary remediation goal
PRRWP	Pentolite Road Red Water Pond
RBRC	risk-based remediation criteria
RBSC	risk-based screening concentration
RfC	reference concentration
RfD	reference dose
RME	reasonable maximum exposure
SAIC	Science Applications International Corporation
SF	slope factor
Shaw	Shaw Environmental, Inc.
TNT	trinitrotoluene
TNTA	TNT Area A
TNTB	TNT Area B
TNTC	TNT Area C
UCL	95th percent upper confidence limit on the arithmetic mean
UF	uncertainty factor
USACE	U.S. Army Corps of Engineers
VOC	volatile organic compound
WARWP	West Area Red Water Ponds
WRS	Wilcoxon Rank-Sum

1.0 Introduction

This baseline human health risk assessment (BHHRA) work plan was prepared to describe the protocol for evaluating human health risks associated with exposure to groundwater underlying and associated with the former Plum Brook Ordnance Works (PBOW), Sandusky, Erie County, Ohio. Specifically, the BHHRA will evaluate groundwater at the following areas:

- TNT Area A (TNTA)
- TNT Area B (TNTB)
- TNT Area C (TNTC)
- Pentolite Road Red Water Pond (PRRWP) Area
- West Area Red Water Ponds (WARWP) Area
- Downgradient areas at the facility boundary.

Risks associated with exposure to other environmental media from the five site areas listed above (not including the facility boundary) were evaluated in previous BHHRAs (IT Corporation [IT], 2001a; 2000a,b). Therefore, the approach and methodologies described in Sections 1.0 through 4.0 of this work plan are intended to apply directly to the evaluation of groundwater risks, but not necessarily to the evaluation of other environmental media. However, for certain receptors the risk characterization sections of the groundwater BHHRA will combine the groundwater risks with those derived from potential exposure to other media (as reported in the previous reports) to estimate overall risks for each respective area (refer to Section 5.4). Combining risks associated with groundwater with those of other environmental media evaluated previously is consistent with earlier PBOW work plans (IT, 1999a, 1998).

This work plan was prepared for the U.S. Army Corps of Engineers (USACE) in partnership with, and supported by, the State of Ohio and is consistent with U.S. Environmental Protection Agency (EPA) guidance. As the lead agency for environmental response actions at PBOW, the USACE is responsible for site investigation and evaluation regarding PBOW, as well as any remedial activities. The Ohio Environmental Protection Agency (OEPA) provides regulatory review, comment, and oversight. This work is being pursued by the USACE under the Defense Environmental Restoration Program—Formerly Used Defense Sites (DERP-FUDS). The environmental restoration of PBOW is a U.S. Army DERP-FUDS project, managed and overseen by the Huntington, West Virginia and Nashville, Tennessee USACE District Offices.

1.1 Facility Description

1.1.1 Location

PBOW is located approximately 4 miles south of Sandusky, Ohio and 59 miles west of Cleveland (Figure 1-1). Although located primarily in 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 (IT, 2001b).

1.2 Background

The 9,009-acre PBOW facility was built in early 1941 as a manufacturing plant for 2,4,6-trinitrotoluene (TNT), dinitrotoluene (DNT), and pentolite (International Consultants Incorporated, 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. The National Aeronautics and Space Administration (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 in 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.

During PBOW operation, 12 process lines were used in the manufacture of explosives: 4 lines at TNTA, 3 lines at TNTB, and 5 lines at TNTC. Manufacturing waste water ("red water") from

these production lines was stored at the two ponds on the WARWP Area and the single pond at the PRRWP Area. The three former production areas, together with the WARWP and PRRWP Areas, are the potential source areas of concern (AOC) to be addressed by this work plan. Note that in this work plan, 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 below.

TNTA. Located in the northeastern portion of PBOW, TNTA occupies approximately 114 acres. TNT manufacturing lines 1 through 4 were located at this area. It is mostly covered with prairie grasses and scrub trees, though 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.

TNTB. TNTB is located in the south-central portion of PBOW and comprises an area of approximately 55 acres. TNT manufacturing 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.

TNTC. Located in the southwestern portion of PBOW, TNTC is densely wooded with small areas of open grassland. It occupies approximately 119 acres. TNT manufacturing lines 8 through 12 were located at this area. TNTC is not used by NASA and one inactive building is present, formerly used by the EPA.

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 1-2). During PBOW operations, “red 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. Pondered 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, which 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 1-2) (SAIC, 1991). During PBOW operations, WARWP received “red water” from TNTC.

Currently, only the “west pond” is present and occupies approximately 4 acres. According to information from Dames & Moore, Inc. (D&M) (1997), the east pond existed from the 1940s until the 1970s, when it was breached in an attempt to drain it. Most of the WARWP Area (i.e., the “west pond”) is typically ponded, with the remainder being marshy. This area is not used by NASA, and no buildings are present.

1.3 Site Use and Groundwater 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.

Two deep or bedrock groundwater aquifer systems are utilized for drinking water in the area: a carbonate aquifer to the west and a shale aquifer to the east (IT, 1997). PBOW is located within the transition of the two systems. A majority of residents in Erie County receive water from public utilities whose sources are surface water. However, there are 8 known permitted private wells within 1 mile downgradient of PBOW; it is unknown if any of these wells are currently used for drinking water or any other purpose. The nearest known downgradient private well is approximately 840 feet northeast of the facility boundary, in the east-middle portion of PBOW (northeast of abandoned well BED-MW27).

Perched groundwater exists within the unconsolidated material atop the bedrock under much of the site. The perched water is isolated, discontinuous, and seasonally dependent, generally resulting in low and undependable production where it exists. Therefore, perched groundwater is not a suitable drinking water source in the vicinity of PBOW. Perched zone-to-bedrock modeling is being performed to determine the potential impact that nitroaromatic contaminants in the perched zone may have on the bedrock water-bearing unit.

Both current and potential future land users are pertinent for the purpose of identifying plausible human receptors and exposure pathways for evaluation in the BHHRA. Current use of the PBOW facility is classified as industrial. It is the desire of NASA to release this site for unrestricted use. D&M (1997) describes potential future uses of all or portions of the facility as:

- 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.

1.4 Protocol for the BHHRA

The BHHRA work plan is based on EPA, USACE, and OEPA guidance, including, but not limited to, the following:

- OEPA, 1993, *Closure Plan Review Guidance for RCRA Facilities*, Interim Final, OEPA Division of Hazardous Waste Management, September 1.
- EPA, 1989a, *Risk Assessment Guidance for Superfund*, Volume I, Human Health Evaluation Manual (Part A), Interim Final, Office of Emergency and Remedial Response, Washington, D.C., EPA/540/1-89/002.
- EPA, 1991a, *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual Supplemental Guidance, Standard Default Exposure Factors*, Interim Final, Office of Solid Waste and Emergency Response, OSWER Directive: 9285.6-03.
- EPA, 1991b, *Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual Part B – Development of Risk-Based Preliminary Remediation Goals*, Interim, Office of Emergency and Remedial Response, Washington, D.C., EPA/540/R-92/003, December.
- EPA, 1992a, *Supplemental Guidance to RAGS: Calculating the Concentration Term*, Office of Solid Waste and Emergency Response, Washington, D.C., Publication 9285.7-081.
- EPA, 1992b, *Dermal Exposure Assessment: Principles and Applications*, Interim Report, Office of Research and Development, Washington, DC, EPA/600/8-91/011B, including Supplemental Guidance dated August 18, 1992.
- EPA, 1992c, "Guidance on Risk Characterization for Risk Managers and Risk Assessors," Memorandum from F. Henry Habicht II, Deputy Administrator, to Assistant Administrators, Regional Administrators, February 26.

- EPA, 1992c, "Guidance on Risk Characterization for Risk Managers and Risk Assessors," Memorandum from F. Henry Habicht II, Deputy Administrator, to Assistant Administrators, Regional Administrators, February 26.
- EPA, 1997a, *Exposure Factors Handbook*, National Center for Environmental Assessment, Washington, DC, EPA/600/P-95/002F, August.
- USACE, 1999, *Risk Assessment Handbook, Volume I: Human Health Evaluation*, Engineer Manual EM 200-1-4.
- EPA, 2004a, *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual [Part E - Supplemental Guidance for Dermal Risk Assessment]*, Final, Office of Superfund Remediation and Technology Innovation, Washington, D.C., EPA/540/R-99/005, July.

1.5 Organization of the BHHRA

The BHHRA will present the methods used, results generated, and the interpretation of these results. The report will be organized as follows:

- **Data Evaluation.** Identifies data sources, evaluates data quality, identifies chemicals of potential concern (COPC), and provides a background screening.
- **Exposure Assessment.** Presents a conceptual site exposure model (CSEM), including contaminant sources, contaminant release mechanisms, receptors and exposure pathways; describes exposure-point concentrations (EPC); and presents methods for calculating chemical intake and contact rates.
- **Toxicity Assessment.** Describes the potential for cancer and/or noncancer human health effects, provides an estimate of the quantitative relationship between the magnitude of dose or contact rate and the probability and/or severity of adverse effects, identifies the toxicity values that are used in the BHHRA, and describes the development of dermal toxicity values.
- **Risk Characterization.** Combines the output of the exposure assessment and toxicity assessment to quantify the risk to each receptor in each AOC. Risks associated with exposure to groundwater from each AOC will be evaluated. Also, overall groundwater risks for the on-site resident and on-site worker will be combined with those associated with exposure to other environmental media (as estimated in previous BHHRA reports or based on cleanup levels attained for soil where appropriate) to estimate overall risks.
- **Uncertainty Analysis.** Identifies uncertainties in all phases of the BHHRA and discusses their individual effects on the risk assessment results, focusing on those

issues that are most likely to have the greatest effect on risk estimates and/or risk management decisions.

- ***Risk-Based Remediation Criteria Development for Groundwater.*** Describes the development of risk-based remediation criteria (RBRC), based on the methodology of the BHHRA and ongoing discussion between OEPA and USACE. Development of RBRCs will consider risks previously identified (for media other than groundwater) and remediation (if any) that has already taken place within a given AOC.
- ***Summary/Conclusions.*** Provides a brief summary of the entire BHHRA, including quantitative results, uncertainties, and pertinent site information. Summary and discussion is focused on those results and issues that are most likely to directly affect site management decisions.
- ***References.*** Provides a complete bibliography of all references used and cited in the BHHRA.

2.0 Data Evaluation

2.1 Selection of Analytical Data

Analytical data for each AOC will be selected based on the representativeness and quality of the data. For inorganics, the sampling method can affect the representativeness of the analytical data; thus, the sampling method is also considered in selection of the analytical data set. The basis for data selection based on sampling method is presented in Section 2.1.1, and the protocol for the evaluation of data quality is presented in Section 2.1.2. Bedrock and overburden wells considered for the evaluation of the respective AOCs, as well as downgradient locations, are identified on Table 2-1.

2.1.1 Sampling Method Considerations

Although groundwater samples have been collected for laboratory analysis dating back to 1989 (IT, 1997), comprehensive site-wide groundwater monitoring began in November 1997 (IT, 1999b). Consistent with the 2004 Groundwater Data Summary and Evaluation Report (Shaw Environmental, Inc. [Shaw], 2004), the BHHRA will include analytical data from November 1997 through the most recent samples collected. The most recent samples were collected for site wells in April 2002, and the downgradient and background wells were most recently sampled in June 2004.

Low-flow groundwater sampling technique was begun in 2001 for monitoring wells with sufficient production to result in laminar flow. The PBOW project team has agreed that low-flow data should be used where possible because low-flow sampling results in samples that more closely represent groundwater conditions in the subsurface. Prior to 2001, all groundwater monitoring wells were sampled by bailer. Similarly, samples that could not be collected using low-flow techniques due to insufficient recharge were collected with a bailer during recent (2001 through 2004) sampling events as well. Whether collected by bailer or low-flow methodology, two fractions for inorganics analysis were taken where possible for each sample: 1) one fraction to be analyzed for dissolved inorganics was filtered in the field at the time of sample collection, and 2) a second sample was collected for analysis without filtration. However, only the unfiltered fraction was collected in cases where well recharge was insufficient and allowed only limited volume for analysis.

For the BHHRA, the following protocol will be used to select monitoring well samples for evaluation of groundwater at each AOC as well as the property boundary:

- All monitoring well analytical data resulting from low-flow samples will be used unless rejected because of a data quality issue (see Section 2.1.2).
- For a monitoring well sampled using both low-flow technique and bailer during different sampling events, the results of the filtered inorganics analysis collected by bailer will be compared to unfiltered low-flow results to determine whether they are generally comparable. The results of the filtered inorganics fraction from the samples collected by bailer will be used in the analysis if they are not substantially lower than the low-flow results; if the filtered bailer sample results are obviously lower than the unfiltered low-flow results, the analytical inorganics results of these filtered samples will not be used. In this case, a similar comparison to low-flow results would be performed using unfiltered samples collected via bailer.
- For all analytes other than inorganics, the results of samples collected by bailer and low-flow technique will be used unless rejected because of data quality issues (Section 2.1.2).

In addition to the monitoring well samples, overburden groundwater samples were collected using direct-push technology from TNTA, TNTC, and the two former red water pond areas. The TNTA and TNTC direct-push samples were collected in September/October 2000 as part of the remedial investigation (IT, 2001b), and the PRRWP and WARWP direct-push samples were collected in June 1998 (IT, 2000b). All validated analytical organic data from these direct-push samples will be used in the BHHRA, unless rejected because of data quality issues (Section 2.1.2). Because the direct-push sampling technique does not include well development or use of a filter pack, the inorganics results from these samples are regarded as unsuitable for risk assessment purposes and will not be used in the BHHRA.

2.1.2 Evaluation of Data Quality

The quality of the analytical data is evaluated to select data for inclusion in the BHHRA. Data quality is expressed by the assignment of qualifier codes during the analytical laboratory quality control process or during data validation that reflect the level of confidence in the data. Some of the more common qualifiers and their meanings are (EPA, 1989a):

- U - Chemical was analyzed for but not detected; the associated value is the sample quantitation limit.
- J - Value is estimated, probably below the contract-required quantitation limit.
- N - The analysis indicates an analyte for which there is presumptive evidence to make a tentative identification.

- NJ - The analysis indicates a “tentatively identified analyte,” and the reported value represents its approximate concentration.
- UJ - The analyte was not detected above the reported sample quantitation limit. However, the reported quantitation limit is approximate and may or may not represent the actual limit of quantitation necessary to accurately and precisely measure the analyte in the sample.
- R - Quality control indicates that the data are unusable (chemical may or may not be present).
- B - The concentration in the sample is not sufficiently higher than concentration in the blank, using the five-times, ten-times (5x, 10x) rule: A chemical is considered a nondetect unless its concentration exceeds five times the blank concentration. For common laboratory contaminants (acetone, 2-butanone [methyl ethyl ketone], methylene chloride, toluene, and the phthalate esters), the sample concentration must exceed ten times the blank concentration to be considered a detection.

“J,” “N,” and “NJ” qualified data will be used in the BHHRA; “R” data and “B” qualified data will not. The handling of “U” qualified data (nondetects) in the BHHRA is described in Section 3.2.1. The use of data with other less-common qualifiers will be evaluated on a case-by-case basis. Generally, data for which the identity of the chemical is unclear are not used in the BHHRA. When confidence is reasonably high that the chemical is present, but the actual concentration is somewhat in question, the data generally are used in the BHHRA.

Some chemicals may be analyzed under two different analytical programs. For example, the DNT isomers are analyzed by EPA Method 8330 for nitroaromatics as well as EPA Method 8270C for semivolatile organic compounds. Risks associated with the reported values from both analyses will be provided in the risk characterization (Section 5.0) and discussed as appropriate in the uncertainty analysis (Section 6.0) together with potential issues such as the relative sensitivities (i.e., differences in respective reporting limits) of the methods.

2.2 Identification of Chemicals of Potential Concern

2.2.1 Risk-Based Screening

Risk-based screening for human health is introduced to focus the assessment on the chemicals that may contribute significantly to overall risk, and to remove from quantification those chemicals whose contribution is clearly inconsequential. In this screen, the maximum detected

concentration (MDC) is compared to the appropriate risk-based screening concentration (RBSC). The units of the MDC and RBSC are the same for each chemical in a given medium; with respect to the PBOW groundwater BHHRA, both the MDC and RBSC have units of micrograms per liter ($\mu\text{g/L}$) in water.

If the MDC of a chemical is less than or equal to its RBSC, then the chemical in this medium is not considered further in the BHHRA because it is very unlikely that chemical concentrations at or below the RBSC would contribute substantially to risk. An analyte is identified as a COPC if its MDC exceeds its RBSC. RBSCs used in the PBOW groundwater BHHRA will be derived from the EPA Region 9 preliminary remediation goals (PRG) table “tap water” values (EPA, 2004b).

PRG values are based on a concentration equal to either an incremental lifetime cancer risk (ILCR) of $1\text{E-}6$ or a noncancer hazard quotient (HQ) of 1, the threshold at (or below) which adverse noncancer effects are regarded as unlikely to occur. For the PBOW groundwater BHHRA, the noncancer values listed in the PRG tables will be multiplied by a factor of 0.1 to provide additional protection for simultaneous exposure to multiple chemicals (EPA, 2004c). This results in groundwater RBSC values associated with an HQ of 0.1. For cancer risk, the PRG values will be used directly as RBSCs in the BHHRA, as they are based on an ILCR of $1\text{E-}6$; acceptable exposure levels are generally concentration levels that represent an excess upper bound lifetime cancer risk to an individual of $1\text{E-}6$ to $1\text{E-}4$ (EPA, 1990). This range is hereinafter referred to as the “risk management range.” Cancer risks associated with PRG values represent the lower end of this range. In the PBOW groundwater BHHRA, the RBSC for a chemical that elicits both cancer and noncancer health effects will be selected based on either a cancer risk of $1\text{E-}6$ or an HQ of 0.1, whichever associated water concentration is lower.

Certain elements are essential human nutrients that are generally regarded as innocuous in levels found in environmental media. These include calcium, chloride, iodine, magnesium, phosphorous, potassium, and sodium. There are no Region 9 PRGs listed for these nutrients. Therefore, none of these essential nutrients will be included as a COPC unless its concentration is judged to be associated with potential adverse human health effects.

2.2.2 Frequency of Detection

When confidence is high that a given chemical is present, the data generally are used in the BHHRA. For most chemicals, their detection is presumptive evidence of their presence. As suggested by EPA (1989a), chemicals that are reported infrequently may be artifacts in the data

that do not reflect the actual presence of the chemical in question. For the BHHRA, chemicals that are reported only at low concentrations in less than 5 percent of the samples from a given medium will be excluded from further consideration, unless their presence is expected based on historical information about the site. Chemicals detected infrequently at high concentrations may identify the existence of contaminant plumes or limited “hot spots” and are retained as COPCs.

2.2.3 Comparison to Background

A number of the chemicals detected in PBOW groundwater may have MDCs that exceed RBSCs, but are part of normal background concentrations associated with groundwater. Such chemicals may include inorganics and polycyclic aromatic hydrocarbons (PAH), a class of organic compounds which form from natural or anthropogenic combustion of organic matter, including fossil fuels, and are generally ubiquitous in the environment. Airborne PAHs associated with non-Department of Defense sources may be deposited on soil and leach to groundwater. BTEX (benzene, ethylbenzene, toluene, and xylenes) compounds may also be associated with background concentrations due to the presence of natural petroleum-derived compounds present in the vicinity of PBOW (see Section 3.1.1).

Site concentrations of chemicals in bedrock groundwater will be compared to those of PBOW background using two different methods: 1) background screening, and 2) statistical data set testing. These methods and their application are described in the following subsections. No suitable background data set exists for overburden wells, so no comparison to background concentrations will be made for perched groundwater.

Inorganics and organics will be treated similarly from a quantitative perspective. However, all organics not eliminated on the basis of RBSC exceedance (Section 2.2.1) or infrequent detection (Section 2.2.2) will be carried through the risk assessment process (exposure assessment, toxicity assessment, and risk characterization). As presented in Section 2.2.3.3, organic compounds will only be eliminated as background-related in the BHHRA through the uncertainty analysis (Section 6.0).

2.2.3.1 Background Screening of Inorganics

Background screening will be applied to each inorganic whose MDC in bedrock groundwater exceeds the RBSC and cannot be characterized as an infrequently detected analyte. In background screening, the MDC is compared to the PBOW chemical-specific background screening concentration (BSC). The derivation of BSCs is described in the 2004 groundwater report (Shaw, 2004). Briefly, BSCs were calculated for use at PBOW based on concentrations

found in background bedrock monitoring wells installed upgradient of PBOW sources. Each BSC is either the MDC or the calculated 95th percent upper tolerance limit of the background data set (based on unfiltered samples collected using low-flow sampling), whichever value is lower (Shaw, 2004).

The screening consists of comparing the MDC of the site data set to the BSC. The chemical is considered for further evaluation if its MDC exceeds BSC for that chemical; further evaluation would include either statistical population testing (Section 2.2.3.2) or immediate inclusion as a COPC and subsequent evaluation in the exposure assessment, toxicity assessment, and risk characterization. The chemical is not regarded as a COPC if its MDC is equal to or less than the BSC.

2.2.3.2 Statistical Data Set Testing of Inorganics

Statistical testing of site inorganics data against the PBOW background data set may be performed for chemicals whose MDCs exceed the respective BSCs and are otherwise identified as COPCs based on RBSC comparison (Section 2.2.1) and frequency of detection (Section 2.2.2). This will be performed using the nonparametric Wilcoxon Rank-Sum statistical test (WRS) (also known as the Mann-Whitney U test). Site data sets will be interpreted as being significantly different from PBOW background if the associated p-level is less than 0.05. WRS statistical output and box and whisker plots of the various data sets will also be included for any analytes tested. WRS will not necessarily be run on all inorganics data otherwise identified as COPCs. For instance, if a site data set of a given inorganic has obviously greater concentrations than the background data set, then the USACE might choose not to run the WRS and carry the analyte through the risk assessment process. Analytes shown by the WRS results to exceed background (or for which the WRS was not run because of obviously higher concentrations in the site data set) are assumed to be site-related, unless a qualitative chemical-specific explanation is presented in the uncertainty analysis (Section 6.0) as to why the analyte should not be regarded as site related.

2.2.3.3 Treatment of Organics

As mentioned in Section 2.2.3, certain organic compounds (BTEX and PAHs) in site groundwater may be attributable to background conditions. The MDC of PAH and BTEX data may also be compared to BSCs (Section 2.2.3.1) and may be compared to PBOW background data using WRS (Section 2.2.3.2), but no organic compound will be summarily screened out. Instead, all detected organic compounds will be carried through the risk assessment process (i.e., exposure assessment, toxicity assessment, risk characterization) unless screened out on the basis

of comparison to RBSCs (Section 2.2.1) or is characterized as infrequently detected (Section 2.2.2). A discussion of background contribution of organics will be presented in the uncertainty analysis (Section 6.0 of the BHHRA).

2.2.4 Role of COPC Screening in the Risk Assessment Process

Figure 2-1 depicts the role of COPC screening as it applies to the risk assessment process. The figure highlights the role of COPC screening, including frequency of detection, risk-based screening, and comparison to background. The figure is not intended as a detailed flow chart of the risk assessment itself, but rather is intended to illustrate how the steps described in Section 2.1 through 2.3 are integrated into the overall risk assessment and the processes that lead to risk management decisions.

2.3 Data Evaluation Summary

A table will be prepared for bedrock groundwater in each AOC with the following information for each detected chemical:

- Chemical name
- Frequency of detection
- Range of detected concentrations
- Range of detection limits
- Arithmetic mean of site concentrations
- 95th percent upper confidence limit on the arithmetic mean (UCL)
- Appropriate RBSC
- Appropriate BSC
- Selection/exclusion of chemical as a COPC.

Similar tables will be provided for overburden groundwater in each AOC for data summary purposes. However, because overburden groundwater is not regarded as a potential source of tap water (Section 1.3), chemicals with MDCs exceeding the RBSCs will be indicated on the tables but will not be identified as COPCs. Likewise, a comparison to background concentrations will not be included on the tables for the overburden wells, because no background data exists for overburden groundwater at PBOW (Section 2.2.3).

3.0 Exposure Assessment

Exposure is the contact by a receptor with a chemical or physical agent. An exposure assessment estimates the type and magnitude of potential exposure of a receptor to COPCs found at or migrating from a site (EPA, 1989a). The following steps are included in an exposure assessment:

- Characterize the physical setting
- Identify the contaminant sources, release mechanisms, and migration pathways
- Identify the potentially exposed receptors
- Identify the potential exposure pathways
- Estimate EPCs
- Estimate chemical intakes or contact rates.

The BHHRA described in this work plan for the five AOCs will characterize exposure to COPCs in groundwater associated with the respective site areas and at the facility boundary. Estimations of potential risks from groundwater exposure will be described in the BHHRA risk characterizations for each groundwater COPC (refer to Section 5.0). As mentioned in Section 1.0, exposure and risks associated with COPCs in soils, surface water, and sediment, as applicable, were estimated for the AOCs in previous BHHRAs (IT, 2001a; 2000a,b). The Scope of Work (USACE, 2001) requires the summation of groundwater risks with those of the environmental media previously evaluated in the risk characterization (see Section 5.4). Therefore, the respective CSEMs described in Section 3.1 include all environmental media evaluated for each AOC (i.e., those evaluated previously, as well as groundwater). However, discussion of the receptors and exposure pathways (Section 3.1.3), methodologies for quantification of EPCs (Section 3.2), and methodologies for quantification of chemical intake (Section 3.3) presented in the text will pertain only to groundwater because pertinent information and calculations based on this information are presented in the previous BHHRAs.

3.1 Conceptual Site Exposure Model

A CSEM provides the basis for identifying and evaluating the potential risks to human health in the BHHRA. A CSEM is constructed from plausible site-use scenarios and the potential exposure pathways. The elements of a CSEM include:

- Source
- Source media (i.e., initially contaminated environmental media)
- Contaminant release mechanisms
- Contaminant transport pathways

- Intermediate or transport media
- Exposure media
- Plausible receptors
- Routes of exposure.

Contaminant release mechanisms and transport pathways are not relevant for direct receptor contact with a contaminated source medium (e.g., ingestion of or dermal contact with groundwater).

Figure 3-1 depicts the CSEM used for each of the three former production areas. The CSEM for each of the two former red water pond areas is depicted on Figure 3-2. The receptors and pathways on Figures 3-1 and 3-2 reflect plausible scenarios developed from information regarding site background and history, topography, climate, and demographics as presented by the site-wide groundwater investigation (IT, 1997). Exposure pathways that are identified as complete (on Figures 3-1 and 3-2) either will be addressed in the groundwater BHHRA or have been addressed by previous BHHRAs, and additional potential receptors not listed on the CSEM figures are briefly discussed in Section 3.1.3.2.

Previous BHHRAs were performed to evaluate exposure to environmental media other than groundwater (IT, 2001a; 2000a,b). Note that the CSEM figures include groundwater as well as the media previously evaluated for the five respective on-site areas. For the current and future off-site resident, only groundwater exposure is evaluated (Figures 3-1 and 3-2). Although a majority of the residents are serviced by municipal water (from surface water sources) there are numerous private groundwater wells in the vicinity, including eight within 1 mile of the facility boundary. Also, based on monitoring wells and a nearby off-site private well sampled as part of the site groundwater investigation, the bedrock units produce adequate quantity. Although natural hydrocarbons are known to be present within the bedrock limestone and shale formations, groundwater underlying the site cannot be summarily excluded for consideration as a tap water source based on natural water quality parameters. Therefore, given the presence of numerous off-site wells and the assumption of unrestricted future land use on site, the development of groundwater for off-site or on-site residential (or on-site worker) use as tap water is regarded as plausible.

3.1.1 Physical Setting

Climate/Meteorology. The climate in the Sandusky area is continental and strongly affected by Lake Erie. July is generally the warmest month (average high and low temperatures of 82 and

65 degrees Fahrenheit [°F], respectively), and January is generally the coldest (average high and low temperatures of 32 and 19°F, respectively) (The Weather Channel, 2004). On average, the first freezing day (low of 32°F or less) occurs in late October (average of 3 per month), and the last freezing day falls in early May (average of 1 per month) (National Oceanic and Atmospheric Administration, 1990). The average annual precipitation for Sandusky is 34.5 inches per year, with a monthly average of more than 3 inches per month falling in April through September and less than 3 inches in each of the other seven months (The Weather Channel, 2004). Precipitation is fairly evenly distributed throughout the year, with the fewest precipitation days (0.01 inch or greater) per month (10) occurring during July, August, September and October, and the most (15) occurring in December and January (City-Data.com, 2004). The mean annual wind speed is 10.3 miles per hour (City-Data.com, 2004), with winds predominantly from the southwest (SAIC, 1991). Sandusky area winters are cloudy with 33 percent sunshine during November through February, as compared with to 65 percent sunshine during the summer months (City-Data.com, 2004).

Geology. Three formations, all of Devonian Age, outcrop across PBOW, each of which was encountered in the upper 100 feet of bedrock at PBOW (Shaw, 2004). The Delaware Limestone is the lowermost formation screened by site wells. It is characterized as a hard, dense, finely crystalline limestone and dolomite. The unit is typically buff colored and usually is described as fossiliferous. In the vicinity of PBOW, quarries mine limestone from the Delaware. Traces of natural petroleum-derived hydrocarbons and hydrogen sulfide are common in area quarries (Shaw, 2004). Overlying the Delaware Limestone is the Olentangy Shale. 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 a 15 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. Only one member of the Ohio Shale is present in the PBOW area, the Huron Shale. 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, 1997).

Soils. The bedrock overburden in Erie County is predominantly glacial till, glacial outwash, or glacial lacustrine (lake) deposits. In the vicinity of PBOW, the soil has been interpreted to be lacustrine. In many areas, the overburden also consists of highly weathered bedrock. The thickness of the overburden ranges from 1 foot to greater than 25 feet. Overburden is thickest on the northern portion of the site in the vicinity of the Reactor Facility Area, where it has filled in a bedrock low (Shaw, 2004).

The soil in the northwest portion of PBOW is placed within the Kibbie-Elnora-Tuscola-Colwood Association that is described as nearly level to gently sloping. This soil is described as somewhat poorly drained, moderately well drained, and very poorly drained soils formed in outwash, lacustrine, and deltaic sediments. Along a strip from west to northeast across the site is the Castalia-Millsdale-Milton-Ritchey Association. This association is described as shallow to moderately deep, nearly level to moderately steep, well drained and very poorly drained soils formed in glacial till, lacustrine sediments, and limestone residuum. Across much of the central portion of the site is the Hornell-Fries-Colwood Association, described as moderately deep to deep, nearly level to gently sloping, somewhat poorly drained to very poorly drained soils formed in glacial till and lacustrine sediments over shale bedrock. At the extreme southeast portion of PBOW is the Pewamo-Bennington Association, described as nearly level to gently sloping, very poorly drained and somewhat poorly drained soils formed from glacial till and lacustrine sediments.

Hydrology. The two main water-bearing zones at PBOW are the overburden and the bedrock. Data collected during the more recent investigations (*TNT Areas A and C Remedial Investigation* [IT, 2001], *Summary Report, Site-Wide Groundwater Monitoring (1997-1998)* [IT, 1999b], and the *Site-Wide Groundwater Investigation Report* [IT, 1997]) indicate that groundwater in the overburden is in discontinuous pockets during dry time periods. In contrast, the bedrock water-bearing zone is saturated year-round. During periods of low precipitation, only limited migration of contaminants would occur in the overburden due to less infiltration. During a wet period, the general flow direction in the overburden water-bearing zone is to the north-northeast largely mirroring surface topography. A hydrogeological study by the U.S. Geological Survey (1992) conducted in the glacial deposits of 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.

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. The conceptual model interprets that bedrock groundwater flow in the Delaware Limestone water-bearing zone migrates and is influenced by the frequency, orientation, density, and connectivity of the fractures.

At PBOW, the bedrock groundwater has been subdivided 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 gallons per minute (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, 1997).

3.1.2 Contaminant Sources, Release Mechanisms, and Migration Pathways Associated with Groundwater

Contaminant sources, release mechanisms and migration pathways are discussed below for the production areas (Figure 3-1) and red water pond areas (Figure 3-2), respectively.

Production Areas. Each production line in the production areas consisted of individual buildings connected by pipelines that carried the reactive materials and the reactions to completion. Contamination involved the inadvertent release of TNT, its precursors, contaminants and residues, and acids or sellite (sodium sulfite made from soda ash and sulfur) from the process lines or drying or packaging areas. Releases occurred to the surface soil as spills and to the subsurface soil from leaking or damaged underground pipes. Releases in the production areas may also have occurred during decontamination and during building and equipment removal processes. Runoff and erosion may have spread contamination over the surrounding surface soil and may have carried contaminants to nearby streams. Infiltration and leaching may have carried contaminants into the subsurface soil and groundwater.

Red Water Ponds. The pond areas received wastewater from TNT production. The PRRWP had received wastewater from TNTA and TNTB which had been treated at Waste Water Disposal Area No. 1. Reportedly, a tile drain carried water from the PRRWP to a ditch which parallels Pentolite Road. The WARWP Area ponds had received wastewater from TNTC that

had been treated at Waste Disposal Area No. 2 (D&M, 1997). Underlying subsurface soils may have been impacted by infiltration; underlying overburden groundwater and possibly bedrock groundwater may have been impacted by leaching. Surrounding surface soil may have been impacted if periods of overflow occurred. Sediment within the drainage ditch along Pentolite Road may have been impacted by contaminants present in the PRRWP surface water that drained into the ditch; groundwater infiltration may also have occurred at this ditch. However, sediment samples collected from this ditch showed no contamination (IT, 2000b).

3.1.3 Groundwater Receptors and Exposure Pathways

3.1.3.1 Overburden Groundwater

As mentioned in Section 1.3, perched groundwater in the vicinity of PBOW is not regarded as a potential source of potable water because it is isolated, discontinuous, and seasonally dependent; these characteristics result in low (if any) and undependable yield. It is possible that construction worker may be exposed to perched water via direct contact; however, such exposure would likely be sporadic and of short duration. Therefore, the BHHRA will not quantitatively evaluate exposure to perched groundwater. As mentioned in Section 1.2, the potential impact of nitroaromatics in perched overburden groundwater on the bedrock unit is being modeled. Specifically, future groundwater concentrations of 2,4-DNT, 2,6-DNT, and TNT are being modeled based on concentrations currently found in the overburden groundwater.

3.1.3.2 Bedrock Groundwater

The following receptors were evaluated to represent the upper bound on bedrock groundwater exposure for all plausibly exposed groups of people at the respective AOCs and the facility boundary.

- **Current on-site.** No current on-site exposure exists. The evaluation of future on-site exposure to groundwater, based on current measured concentrations (as described below), would be appropriate for the evaluation of current on-site receptors, if such exposure existed.
- **Current off-site.** Based on measured concentrations at the five boundary wells and well BED-MW30, assuming a just off-site resident. Data for all six wells (Figure 1-2) will be combined into a single evaluation. (Note that downgradient well BED-MW30 was added to the evaluation because it exhibited low levels of nitroaromatics.)
- **Future on-site.** Based on measured concentrations at each of the five PBOW AOCs (five separate evaluations) described in this work plan. Future receptors are

an on-site worker and on-site resident. Additionally, risks associated with modeled future groundwater concentrations for 2,4-DNT, 2,6-DNT and TNT will be estimated and discussed in the uncertainty analysis (Section 6.0).

- **Future off-site.** Modeled concentrations of 2,4-DNT, 2,6-DNT, and TNT at just off-site locations of highest concentrations, for up to five areas based on bedrock groundwater flow directions.

If on-site groundwater were to be developed as a tap water source, other potential future groundwater receptors may include short-term (e.g., construction) workers or site visitors. However, the levels of exposure to these would be shorter in duration and/or frequency than that of an on-site worker or resident. Therefore, the on-site worker and resident receptor represent an upper bound on exposure for all potential receptors.

Quantitative evaluations of exposure to groundwater COPCs are based on a reasonable maximum exposure (RME) approach for each receptor. The intent of the RME approach is to estimate the highest exposure level that could reasonably be expected to occur, but not necessarily the worst possible case (EPA, 1989a, 1991a). It is interpreted as reflecting the 90 to 95th percentile on exposure. In keeping with EPA (1991a) guidance, variable values chosen for a baseline RME scenario for intake rate, exposure frequency (EF) and exposure duration (ED) are generally upper bounds. Other variables, e.g., body weight (BW) and exposed skin surface area, are generally central or average values. In the case of contact rates consisting of multiple components (e.g., dermal contact with water, which consists of a permeability coefficient [K_p] and exposure time [ET]) only one variable, (e.g., K_p) needs to be an upper bound. The conservativeness built into individual variables is designed to result in contact rate estimates that are more than adequately health-protective.

The averaging time (AT) for noncancer evaluation is computed as the product of ED (years) times 365 days/year, to estimate an average daily dose over the entire exposure period (EPA, 1989a). For cancer evaluation, AT is the product of 70 years (25,550 days), the assumed human lifetime, multiplied by 365 days/year, to estimate an average daily dose prorated over a lifetime, regardless of the frequency or duration of exposure. This methodology assumes that the risk from short-term exposure to a high dose of a given carcinogen is equivalent to long-term exposure to a correspondingly lower dose, provided that the total lifetime doses are equivalent. This approach is consistent with current EPA (1986) policy of carcinogen evaluation, although it introduces considerable uncertainty into the cancer evaluation component of the BHHRA.

The only receptors evaluated under the exposure scenarios evaluated for PBOW groundwater are the resident (evaluated for current off-site, future on-site, and future off-site conditions) and the future on-site worker. Exposure assumptions and parameter values specific to the resident and worker are described in the paragraphs that follow. The fraction of tap water intake/exposure (refer to “FI” term in the equations in Section 3.2) attributed to groundwater from each PBOW AOC (as well as the off-site locations) is 1.0 for each receptor. Exposure parameters and parameter values are summarized in Table 3-1.

Resident. The resident is assumed to be exposed to groundwater as household tap water and, for volatile compounds, air concentrations that are associated with groundwater use in the residence. Exposure assumptions and parameter values for the current off-site resident, future on-site resident, and future off-site resident are identical. Cancer and noncancer assessments will be performed for both an adult and child. The evaluations will assume 30 years of exposure: 24 years as a 70-kilogram (kg) adult (EPA, 1991a) and 6 years as a 15-kg child (EPA, 2004c). For cancer effects, the adult and child effects will be summed together; for noncancer effects, the child and adult will be evaluated separately. An EF of 350 days per year (EPA, 1991a) will be used for adult and child residential pathways.

Drinking water ingestion rates for the adult of 2 liters per day (L/day) (EPA, 1991a) and for the child of 1 L/day (EPA, 2004c) will be assumed. Both the child and adult resident are assumed to be dermally exposed to COPCs in groundwater while bathing/showering. The child will be assumed to bathe for 20 minutes per day (0.333 hour/day) (EPA, 1997a). The adult will be assumed to shower for 12 minutes per day (0.2 hour/day) (EPA, 2003a). Inhalation rates of 0.833 cubic meters per hour (m³/hour) for the adult (EPA, 1991a) and 0.416 m³/hour for the child (EPA, 2004c) will be used. Because the *Exposure Factors Handbook* (EPA, 1997a) lists a 90th percentile for time spent in a residence as over 23 hours per day, it will be conservatively assumed that the resident spends 24 hours per day in the house.

On-Site Worker. In the future land-use scenario, a site worker may be exposed to groundwater, which theoretically could be developed as a source of drinking water. His drinking water ingestion rate is assumed to be 1 L/day (EPA, 1991a). He may also experience dermal contact with groundwater used to clean equipment and to rinse dust or perspiration from his body. For this evaluation, it was assumed that the head, forearms, and hands, approximately 3,300 square centimeters (EPA, 2004a), would be exposed intermittently for up to 1 hour per day. Because exposure was assumed to be intermittent, rather than continuous, organic chemical

uptake across the dermis would not reach steady state, which guides selection of the EPA (2004a) model to be used to quantify this pathway (Section 3.3.3).

3.2 Quantification of Exposure-Point Concentrations

The EPC is an estimate of the concentration of a COPC in a given medium to which a receptor may be exposed over the duration of the exposure. An EPC may be based on media concentrations that have been directly measured, or it may be derived based on environmental medium-to-medium transport modeling. The EPCs of COPCs in groundwater were statistically derived values, based on measured analytical data. Concentrations of COPCs in air were not measured (and in the case of groundwater volatilization or future exposure scenarios, cannot reasonably be measured), but were based on models, which use the EPCs of COPCs in groundwater as input values.

3.2.1 Groundwater Concentrations

Generally, the UCL or the MDC of the measured concentrations, whichever is lower, is selected as the groundwater EPC and is understood to represent a conservative estimate of average concentration for use in the exposure assessment for RME evaluation. Unusually high detected values are included in the calculation of the UCL concentration. Inclusion of these high values increases the statistical variability and the overall conservativeness of the risk estimate.

Exposure to an environmental medium is generally assumed to be random, and the EPC should be the arithmetic average encountered over the ED (EPA, 1989a). Therefore, the population mean concentration, if known, would be the ideal value selected as the EPC. The sample mean is an obvious estimate of the population mean. However, uncertainties exist as to how well the sample mean represents the population mean. Therefore, EPA (1989a) has recommended the inclusion of an upper confidence limit of 95 percent on the sample mean for RME evaluation. The following paragraphs describe the statistical approaches and the models used to derive EPCs for groundwater. This is basically the same statistical approach used in the previous BHHRA for soils and other environmental media (IT, 2001a; 2000a,b).

The nature of the statistical distribution (normal, lognormal, nonparametric) is determined for COPC data sets having five or more samples with the Shapiro-Wilks test (EPA, 1992d). Either a normal or lognormal UCL is calculated, whichever provides the better fit in the Shapiro-Wilks test. Where either distribution provides virtually the same level of fit (at $p < 0.05$) based on the Shapiro-Wilks test results, a normal distribution is selected because the UCL calculation for the normal distribution has greater mathematical stability (EPA, 1997b; Hardin and Gilbert, 1993).

A nonparametric confidence limit is calculated when the data fit neither a normal or lognormal distribution.

The UCL is calculated for a normal distribution as follows (EPA, 1992a):

$$UCL = \bar{x} + t_{1-\alpha, n-1} (s/\sqrt{n}) \quad \text{Eq. 3.1}$$

where:

- UCL = upper 95th confidence limit on the arithmetic mean concentration (calculated)
- \bar{x} = sample arithmetic mean
- t_1 = critical value for Student's *t*-test
- α = 0.05 (95 percent confidence limit for a one-tailed test)
- n = number of samples in the data set
- s = sample standard deviation.

The UCL is calculated for a lognormal distribution as follows (Gilbert, 1987):

$$UCL = e^{\left[\bar{y} + (0.5 \cdot s_y^2) + \left[H_{0.95} \cdot \frac{s_y}{(n-1)^{0.5}} \right] \right]} \quad \text{Eq. 3.2}$$

where:

- UCL = upper 95th confidence limit on the arithmetic mean concentration (calculated)
- \bar{y} = $\sum y/n$ = sample arithmetic mean of the log-transformed data, $y = \ln x$
- s_y = sample standard deviation of the log-transformed data
- n = number of samples in the data set
- $H_{0.95}$ = value for computing the one-sided upper 95 percent confidence limit on a lognormal mean from standard statistical tables (Land, 1975).

A nonparametric confidence limit is calculated when the distribution fits neither a normal or lognormal distribution. The nonparametric UCL is the 95th percent upper confidence limit on the median, rather than the mean, because the median is a better estimate of central tendency for a nonparametric distribution. The rank order of the data point selected as the UCL is estimated from the following equation (Gilbert, 1987):

$$u = p(n+1) + Z_{1-\alpha} \sqrt{np(1-p)} \quad \text{Eq. 3.3}$$

where:

u	=	rank order of value selected as UCL, calculated
p	=	percentile corresponding to the arithmetic mean
n	=	number of samples in the data set
α	=	confidence limit (95 percent)
$Z_{1-\alpha}$	=	normal deviate variable.

The concentration corresponding to the calculated rank order UCL is used as the EPC for nonparametric data, unless this value is less than the mean concentration. It is theoretically possible using the lognormal and nonparametric methods that the UCL for a given COPC may be less than the arithmetic mean concentration. If such an instance were to occur, the arithmetic mean concentration would be used as the EPC; the COPC data would be specifically discussed in the uncertainty analysis (Section 6.0) as appropriate.

Analytical results are presented as "nondetects" ("U" qualifier) whenever chemical concentrations in samples do not exceed the reporting limits. To apply the previously mentioned statistical procedures to a data set with nondetects, a concentration value must be assigned to nondetects. Nondetects are assumed to be present at one-half the reporting limit, although judgment is used in those cases where matrix interference or other phenomena drive the reporting limits unusually high (EPA, 1989a). If any nondetects are eliminated from the data set due to high reporting limits that would otherwise skew the EPC, these samples will be discussed in the uncertainty analysis (Section 6.0).

3.2.2 Concentrations in Household Air from Groundwater Use

Inhalation of volatile organic compounds (VOC) released from groundwater used as tap water will be evaluated, if applicable, for the on-site and off-site resident scenarios. Chemicals that have a Henry's Law value exceeding 1E-05 atmospheres per cubic meter (m^3) per mole and a molecular weight less than 200 grams per mole are considered to be VOCs are subject to evaluation via this pathway. Other groundwater contaminants may be evaluated on a case-by-case basis for their potential contribution to risk via the inhalation pathway based on the degree of departure from the Henry's Law and molecular weight criteria, groundwater concentration, and toxicity.

The simple whole-house tap water-to-air model described in the Part B of the human health evaluation manual (HHEM) (EPA, 1991b) will be used in the BHHRA. This model was selected based on correspondence between the OEPA (2004) and the USACE. Part B of the HHEM recommends a volatilization constant of 0.0005 for the total concentrations of all VOCs detected in groundwater; the conversion is characterized by the following equation:

$$C_a = C_{gw} \cdot 0.001 \frac{mg}{\mu g} \cdot K_{wa} \cdot 1,000 \frac{L}{m^3} \quad \text{Eq. 3-4}$$

where:

- C_a = Modeled concentration in air (milligrams per cubic meter [mg/m^3])
- C_{gw} = Groundwater EPC ($\mu g/L$)
- K_{wa} = tap water-to-air volatilization constant (0.0005 [unitless]: EPA, 1991b)

Implicit in HHEM Part B application of this model are the following: 1) a family of four uses the groundwater as the sole source of household tap water; 2) the volume of the house is $150 m^3$; 3) the daily groundwater use is 720 L/day; 4) 50 percent of VOCs in tap water volatilize to household air; and 5) exchange rate of the house is $0.25 m^3$ per hour (EPA, 1991b). The EPA (1997a) *Exposure Factors Handbook* lists values different from some of these assumed by HHEM Part B. If appropriate, this pathway will also be evaluated in the BHHRA using alternate values from the *Exposure Factors Handbook*.

3.2.3 Concentrations of VOCs in Groundwater: Resident Dermal Uptake

Volatilization of VOCs from household water reduces the concentration remaining available for dermal contact. As mentioned in Section 3.2.2, the HHEM Part B tap water-to-air model assumes that 50 percent of the VOC concentrations are released to household air. Thus, the concentrations of VOCs remaining in the water after volatilization occurs is calculated by difference as follows:

$$C_d = C_{gw} \cdot (1 - F_v) \quad \text{Eq. 3-5}$$

where:

- C_d = concentration of VOC in household water available for dermal exposure (milligrams per liter [mg/L], calculated)
- C_{gw} = concentration of VOC in groundwater (mg/L)
- F_v = fraction of VOCs volatilized to air, (0.5, unitless).

Only the concentration remaining in tap water (C_d) is assumed to be available for contact with the skin during bathing/showering.

3.3 Quantification of Chemical Intakes

This section describes the models used to quantify doses or intakes of the COPC by the exposure pathways identified in Section 3.1.2, using the exposure parameter values described in Section

3.1.3. Models were taken or modified from EPA (1989a) unless otherwise indicated. Intakes will be calculated for both cancer and noncancer evaluations. Therefore, the AT variable shown in the following equations is replaced with AT_n for noncancer calculations ($365 \times ED$), and with AT_c (25,550 days) for the cancer calculations. Intake values will be based on the EPCs (Section 3.2) and the equations discussed below for the respective exposure pathways.

3.3.1 Ingestion of COPC in Groundwater

The ingested dose of COPC in groundwater is estimated from the equation:

$$I_w = \frac{(C_w)(IR_w)(FI_w)(EF)(ED)}{(BW)(AT)} \quad \text{Eq. 3.6}$$

where:

- I_w = ingested dose of COPC in groundwater (milligrams per kilogram per day [mg/kg-day], calculated)
- C_w = concentration of COPC in groundwater (mg/L)
- IR_w = drinking water ingestion rate (L/day)
- FI_w = fraction of exposure attributed to site groundwater (unitless)
- EF = exposure frequency (days/year)
- ED = exposure duration (years)
- BW = body weight (kg)
- AT = averaging time (days).

3.3.2 Inhalation of COPC from Air

The following equation is used to estimate the inhaled dose of COPCs in air as a result of volatilization from tap water. Air concentrations used in this equation are modeled (Section 3.2.2).

$$I_{sa} = \frac{(C_a)(IR_a)(ET_a)(EF)(ED)}{(BW)(AT)} \quad \text{Eq. 3.7}$$

where:

- I_a = inhaled dose of COPC (mg/kg-day, calculated)
- C_a = concentration of COPC in air from dust and volatilization (mg/m^3)
- IR_a = inhalation rate (m^3/hour)
- ET_a = exposure time to VOCs in air (hours/day)
- EF = exposure frequency (days/year)
- ED = exposure duration (years)

BW = body weight (kg)
 AT = averaging time (days).

3.3.3 Dermal Contact with COPC in Water

Unlike the methodologies for estimating inhaled or ingested doses of a COPC, which quantify the dose presented to the barrier membrane (the pulmonary or gastrointestinal mucosa, respectively), the dermal dose is estimated as the dose that crosses the skin and is systematically absorbed. For this reason, dermal toxicity values are also based on absorbed dose. The absorbed dose of COPCs from groundwater are estimated using the following equation (EPA, 2004a):

$$DAD = \frac{(DA)(SA)(EF)(ED)(EV)}{(BW)(AT)} \quad \text{Eq. 3.8}$$

where:

DAD = average dermally absorbed dose of COPC (mg/kg-day, calculated)
 DA = dose absorbed per unit body surface area per event (milligrams per square centimeter per event [mg/cm²-event])
 SA = surface area of the skin available for contact with environmental medium (soil, groundwater, sediment or surface water) (square centimeters [cm²])
 EF = exposure frequency (days/year)
 ED = exposure duration (years)
 EV = events per day
 BW = body weight (kg)
 AT = averaging time (days).

Quantification of dermal uptake of constituents from water depends on a K_p , which describes the rate of movement of a constituent from water across the dermal barrier to the systemic circulation (EPA, 1992b). Separate calculation methods are applied to estimate the DA term (defined above) for inorganic and organic chemicals in water. For inorganic chemicals, DA is calculated from the following equation:

$$DA = (C_w)(K_p)(ET_w)(CF) \quad \text{Eq. 3.9}$$

where:

DA = dose absorbed per unit body surface area per event (mg/cm²-event, calculated)
 C_w = concentration of COPC in water (mg/L)
 K_p = permeability coefficient (centimeters per hour [cm/hour])

ET_w = time of exposure (hours/event)
 CF = conversion factor (0.001 liters per cm^3).

K_p values are available for some inorganics (EPA, 2004b). A default K_p value of 0.001 cm/hour (EPA, 2004b) will be used for those inorganics for which no chemical-specific values were available.

K_p values for organic chemicals vary by several orders of magnitude, largely dependent on lipophilicity, expressed as a function of the octanol/water partition coefficient (K_{ow}). Because the stratum corneum (the outer skin layer) is rich in lipid content, it may act as a sink, initially reducing the transport of chemical to the systemic circulation. With continued exposure and the attainment of steady state conditions, the rate of transfer to the systemic circulation increases. Therefore, different equations are used to estimate DA, depending on whether the ET is less or greater than the estimated time to reach steady state. Dermal exposure to groundwater is expected to generally be of relatively short duration (e.g., limited to bathing/showering time and/or intermittent hand and face washing). Therefore, it is assumed that steady state is not reached, which is the usual case for relatively short ETs. Under these conditions, DA is calculated from the following equation (EPA, 2004a):

$$DA = 2(FA)(K_p)(C_w)(CF) \sqrt{\left(\frac{6\tau(ET_w)}{\pi}\right)} \quad \text{Eq. 3.10}$$

where:

DA = dose absorbed per unit body surface area per day (mg/cm^2 -event, calculated)
 FA = fraction available post-exposure for absorption in the stratum corneum
 K_p = permeability coefficient (cm/hour)
 C_w = concentration of constituent in water ($\mu g/L$) (Note that for volatiles in shower water the C_w should be the concentration remaining after volatilization from the water droplet.)
 CF = conversion factor (0.001 liter per cm^3 [L/cm^3])
 τ = time for concentration of contaminant in stratum corneum to reach steady state (hours)
 ET_w = exposure time to groundwater (hours).

When available, values for K_p and τ will be taken from EPA (2004a). For organics that have no K_p values listed, the values will be calculated using Equation 3.11 (EPA, 2004a):

$$\text{Log}(K_p) = -2.80 + 0.66(\log K_{ow}) - 0.0056(MW) \quad \text{Eq. 3.11}$$

where:

- K_p = permeability coefficient (cm/hour, calculated)
- $\log K_{ow}$ = log of the octanol/water partition coefficient (unitless)
- MW = molecular weight.

Where values for τ are not available, they will be calculated using Equation 3.12 (EPA, 1992a). Values of K_p and τ to be used in the BHHRA will be appended.

$$\tau = \frac{L_{sc}}{6 \times 10^{(-2.72 - 0.0061 * MW)}} \quad \text{Eq. 3.12}$$

where:

- τ = time for concentration of contaminant in stratum corneum to reach steady state (hours, calculated)
- L_{sc} = effective thickness of the stratum corneum (0.001 centimeters)
- MW = molecular weight.

3.3.4 Inhalation of Air Containing VOCs from Groundwater

Equation 3.13 is used to estimate the inhaled dose of VOCs in air from household use of groundwater. The inhaled dose is estimated using the following equation.

$$I_{wa} = \frac{(C_{wa})(IR_a)(FI_{wa})(ET_{wa})(EF)(ED)}{(BW)(AT_n)} \quad \text{Eq. 3.13}$$

where:

- I_{wa} = inhaled dose of COPC (mg/kg-day, calculated)
- C_{wa} = concentration of VOCs in air from volatilization (mg/m³)
- IR_a = inhalation rate (m³/hour)
- FI_{wa} = fraction of exposure attributed to contaminated medium (unitless)
- ET_{wa} = exposure time to VOCs in air (hours/day)
- EF = exposure frequency (days/year)
- ED = exposure duration (years)
- BW = body weight (kg)
- AT_n = averaging time for noncancer (days).

4.0 Toxicity Assessment

Toxicity is defined as the ability of a chemical to induce adverse effects in biological systems.

The purpose of the toxicity assessment is two-fold:

- Identify the cancer and noncancer effects that may arise from exposure of humans to the COPC (hazard assessment).
- Provide an estimate of the quantitative relationship between the magnitude and duration of exposure and the probability or severity of adverse effects (dose-response assessment).

The latter is accomplished by the derivation of cancer and noncancer toxicity values, as described in the following section.

4.1 Evaluation of Carcinogenicity

A few chemicals are known, and many more are suspected, to be human carcinogens. The evaluation of the potential carcinogenicity of a chemical includes both a qualitative and a quantitative aspect (EPA, 1986). The qualitative aspect is a weight-of-evidence evaluation of the likelihood that a chemical might induce cancer in humans. EPA (1986) recognizes six weight-of-evidence group classifications for carcinogenicity:

- **Group A - Human Carcinogen:** human data are sufficient to identify the chemical as a human carcinogen.
- **Group B1 - Probable Human Carcinogen:** human data indicate that a causal association is credible, but alternative explanations cannot be dismissed.
- **Group B2 - Probable Human Carcinogen:** human data are insufficient to support a causal association, but testing data in animals support a causal association.
- **Group C - Possible Human Carcinogen:** human data are inadequate or lacking, but animal data suggest a causal association, although the studies have deficiencies that limit interpretation.
- **Group D - Not Classifiable as to Human Carcinogenicity:** human and animal data are lacking or inadequate.
- **Group E - Evidence of Noncarcinogenicity to Humans:** human data are negative or lacking, and adequate animal data indicate no association with cancer.

The toxicity value for carcinogenicity, called a cancer slope factor (SF), is an estimate of potency. Potency estimates are developed only for chemicals in Groups A, B1, B2 and C, and only if the data are sufficient. The potency estimates are statistically derived from the dose-response curve from the best human or animal study or studies of the chemical. Although human data are often considered to be more reliable than animal data because there is no need to extrapolate the results obtained in one species to another, most human studies have one or more of the following limitations:

- The duration of exposure is usually considerably less than lifetime.
- The concentration or dose of chemical to which the humans were exposed can be approximated only crudely, usually from historical data.
- Concurrent exposure to other chemicals frequently confounds interpretation.
- Data regarding other factors (tobacco, alcohol, illicit or medicinal drug use, nutritional factors and dietary habits, heredity) are usually insufficient to eliminate confounding or quantify its effect on the results.
- Most epidemiologic studies are occupational investigations of workers, which may not accurately reflect the range of sensitivities of the general population.
- Most epidemiologic studies lack the statistical power (i.e., sample size) to detect a low, but chemical-related increased incidence of tumors.

Most potency estimates are derived from animal data, which present different limitations:

- It is necessary to extrapolate from results in animals to predict results in humans, usually done by estimating an equivalent human dose from the animal dose.
- The range of sensitivities arising from genotypic and phenotypic diversity in the human population is not reflected in the animal models ordinarily used in cancer studies.
- Usually very high doses of chemical are used, which may alter normal biology, creating a physiologically artificial state and introducing substantial uncertainty regarding the extrapolation to the low-dose range expected with environmental exposure.
- Individual studies vary in quality (e.g., duration of exposure, group size, scope of evaluation, adequacy of control groups, appropriateness of dose range, absence of concurrent disease, sufficient long-term survival to detect tumors with long induction or latency periods).

The SF is usually expressed as "extra risk" per unit dose, that is, the additional risk above background in a population corrected for background incidence. It is calculated using the following equation:

$$(P_{(d)} - P_{(0)}) / (1 - P_{(0)}) \quad \text{Eq. 4.1}$$

where:

- $P_{(d)}$ = the probability of cancer associated with dose = 1 mg/kg-day
- $P_{(0)}$ = the background probability of developing cancer at dose = 0 mg/kg-day.

The SF is expressed as risk per milligrams per kilogram per day ($[\text{mg/kg-day}]^{-1}$). In order to be appropriately conservative, the SF is usually the 95 percent upper-bound on the slope of the dose-response curve extrapolated from high (experimental) doses to the low-dose range expected in environmental exposure scenarios. EPA (1986) assumes that there are no thresholds for carcinogenic expression; therefore, any exposure represents some quantifiable risk.

The oral SF is usually derived directly from the experimental dose data, because oral dose is usually expressed as mg/kg-day. When the test chemical was administered in the diet or drinking water, oral dose first must be estimated from data for the concentration of the test chemical in the food or water, food or water intake data, and BW data.

The Integrated Risk Information System (IRIS) (EPA, 2005) expresses inhalation cancer potency as a unit risk based on concentration, or risk per milligram of chemical per m^3 of ambient air. Because cancer risk characterization requires a potency expressed as risk per mg/kg-day, the unit risk must be converted to the mathematical equivalent of an inhalation cancer SF, or risk per unit dose. Since the inhalation unit risk is based on continuous lifetime exposure of an adult human (assumed to inhale 20 m^3 of air per day and to weigh 70 kg) the mathematical conversion consists of multiplying the unit risk (per mg/m^3) by 70 kg and by 1,000 micrograms per milligram, and dividing the result by 20 m^3 per day.

Cancer toxicity values and sources will be provided in the PBOW BHHRA in table format.

4.2 Evaluation of Noncarcinogenic Effects

Many chemicals, whether or not associated with carcinogenicity, are associated with noncarcinogenic effects. The evaluation of noncancer effects (EPA, 1989b) involves:

- Qualitative identification of the adverse effect(s) associated with the chemical; these may differ depending on the duration (acute or chronic) or route (oral or inhalation) of exposure
- Identification of the critical effect for each duration of exposure (i.e., the first adverse effect that occurs as dose is increased)
- Estimation of the threshold dose for the critical effect for each duration of exposure
- Development of an uncertainty factor (UF); i.e., quantification of the uncertainty associated with interspecies extrapolation, intraspecies variation in sensitivity, severity of the critical effect, slope of the dose-response curve, and deficiencies in the database, in regard to developing a reference dose (RfD) for human exposure
- Identification of the target organ(s) for the critical effect for each route of exposure.

These information points are used to derive an exposure route- and duration-specific toxicity value called an RfD, expressed as mg/kg-day, which is considered to be the dose for humans, with uncertainty of an order of magnitude or greater, at which adverse effects are not expected to occur. Mathematically, it is estimated as the ratio of the threshold dose to the UF. For purposes of risk assessment, chronic exposure is defined as equal to or greater than 7 years, i.e., at least 10 percent of expected life span; subchronic exposure is defined as 2 weeks to 7 years.

IRIS (EPA, 2005) expresses the inhalation noncancer reference value as a reference concentration (RfC) in units of mg/m³. Because noncancer risk characterization requires a reference value expressed as mg/kg-day, the RfC must be converted to an inhalation RfD. Since the inhalation RfC is based on continuous exposure of an adult human (assumed to inhale 20 m³ of air per day and to weigh 70 kg), the mathematical conversion consists of multiplying the RfC (mg/m³) by 20 m³/day and dividing the result by 70 kg.

RfD and RfC values are derived for both chronic and subchronic exposure. Under the assumption of monotonicity (incidence, intensity, or severity of effects can increase, but cannot decrease, with increasing magnitude or duration of exposure), a chronic RfD may be considered sufficiently protective for subchronic exposure, but a subchronic RfD may not be protective for

chronic exposure. Currently, subchronic RfD values exist for few chemicals. Subchronic RfD values can be derived from chronic RfD values as follows:

- If the UF applied in the derivation of the chronic RfD does not provide for expansion from subchronic to chronic exposure (e.g., if the chronic RfD was derived from a chronic study), the chronic RfD is adopted as being sufficiently protective for subchronic exposure.
- If the UF applied in the derivation of the chronic RfD contains a component to expand from subchronic to chronic exposure, the subchronic RfD is derived by multiplying the chronic RfD by the factor used to expand from subchronic to chronic exposure (e.g., if a factor of 10 was used to expand from subchronic to chronic exposure, the subchronic RfD will be 10 times larger than the chronic RfD).

Oral and dermal (discussed in Section 4.3) RfDs, as well as RfCs and inhalation RfDs will be provided in the groundwater BHHRA in table format.

4.3 Dermal Toxicity Values

Dermal RfDs and SFs are derived from the corresponding oral values, provided there is no evidence to suggest that dermal exposure induces exposure route-specific effects that are not appropriately modeled by oral exposure data. In the derivation of a dermal RfD, the oral RfD is multiplied by the gastrointestinal absorption factor (GAF), expressed as a decimal fraction. The resulting dermal RfD, therefore, is based on absorbed dose. The RfD based on absorbed dose is the appropriate value with which to compare a dermal dose, because dermal doses are expressed as absorbed rather than exposure doses. The dermal SF is derived by dividing the oral SF by the GAF. The oral SF is divided, rather than multiplied, by the GAF because the SF is expressed as a reciprocal dose.

4.4 Target Organ Toxicity

As a matter of science policy, EPA assumes dose and effect to be additive for noncarcinogenic effects (EPA, 1989a). This assumption provides the justification for adding the HQ or hazard indices (HI) in the risk characterization for noncancer effects (Section 5.2) resulting from exposure to multiple chemicals, pathways, or media. However, EPA (1989a) acknowledges that adding all HQ or HI values may overestimate hazard, because the assumption of additivity is probably appropriate only for those chemicals that exert their toxicity by the same mechanism.

Mechanisms of toxicity data sufficient for predicting additivity with a high level of confidence are available for very few chemicals. In the absence of such data, EPA (1989a) assumes that chemicals that act on the same target organ may do so by the same mechanism of toxicity; that is, the target organ serves as a surrogate for mechanism of toxicity. When total HI for all media for a receptor exceeds 1 due to the contributions of several chemicals, it is appropriate to segregate the chemicals by route of exposure and mechanism of toxicity (i.e., target organ) and estimate separate HI values for each target organ.

As a practical matter, since human environmental exposures are likely to involve near- or sub-threshold doses, the target organ chosen for a given chemical is the one associated with the critical effect. If more than one organ is affected by a given chemical at the threshold, then the affected target organs are selected for this chemical. The target organ is also selected on the basis of duration of exposure (i.e., the target organ for chronic or subchronic exposure to low or moderate doses is selected rather than the target organ for acute exposure to high doses) and route of exposure. Because dermal RfD values are derived from oral RfD values, the oral target organ is adopted as the dermal target organ. For some chemicals, no target organ is identified. This occurs when no adverse effects are observed or when adverse effects such as reduced longevity or growth rate are not accompanied by recognized organ- or system-specific functional or morphologic alteration. Target organs for the oral and inhalation pathway will be provided in the groundwater BHHRA.

4.5 Sources of Toxicity Information Used in the Risk Assessment

Toxicity values will be selected for use in the BHHRA based on the OSWER Directive 9285.7-53 (EPA, 2003b) which prescribes the following hierarchy:

- **Tier 1** values: IRIS (EPA, 2005) database.
- **Tier 2** values: EPA's provisional peer-reviewed toxicity values. The provisional peer-reviewed toxicity values are developed by the Office of Research and Development, the National Center for Environmental Assessment, and the Superfund Health Risk Technical Support Center on a chemical-specific basis when requested by the Superfund program.
- **Tier 3** values: Other toxicity values from additional EPA and non-EPA sources of toxicity information. As stated in the OSWER directive, "priority should be given to those sources of information that are the most current, the basis for which is transparent and publicly available, and which have been peer reviewed." Two common examples of Tier 3 values are the USEPA's Health Effects Assessment

Summary Tables (EPA, 1997c) and the California Environmental Protection Agency (2005) Office of Environmental Health Hazard Assessment Toxicity Criteria Database.

GAFs, used to derive dermal RfD values and SFs from the corresponding oral toxicity values, are obtained from the following sources:

- Oral absorption efficiency data compiled by the National Center for Environmental Assessment for the Superfund Health Risk Technical Support Center of EPA
- Federal agency reviews of the empirical data, such as Agency for Toxic Substances and Disease Registry Toxicological Profiles and various EPA criteria documents
- Other published reviews of the empirical data
- The primary literature.

GAFs obtained from reviews are compared to empirical (especially more recent) data, when possible, and are evaluated for suitability for use for deriving dermal toxicity values from oral toxicity values. The suitability of the GAF increases when the following similarities are present in the oral pharmacokinetic study from which the GAF is derived and in the key toxicity study from which the oral toxicity value is derived:

- The same strain, sex, age, and species of test animal were used.
- The same chemical form (e.g., the same salt or complex of an inorganic element or organic compound) was used.
- The same mode of administration (e.g., diet, drinking water or garbage vehicle) was used.
- Similar dose rates were used.

The most defensible GAF for each chemical will be used in the BHHRA.

5.0 Risk Characterization

Risk characterization is the process of applying numerical methods and professional judgment to determine the potential for adverse human health effects to result from the presence of site-specific contaminants. This is done by combining the intake rates estimated during the exposure assessment, with the appropriate toxicity information identified during the toxicity assessment. Noncancer hazards and cancer risks are characterized separately.

Quantitative expressions are calculated during risk characterization that describe the probability of developing cancer (ILCRs), or the nonprobabilistic comparison of estimated dose with an RfD for noncancer effects (HQs and HIs). Quantitative estimates are developed for individual chemicals, exposure pathways, and exposure media for each receptor. These quantitative risk characterization expressions, in combination with qualitative information, are used to guide risk management decisions. Risk characterization, as described in this section, is applied only to COPC.

Generally, the risk characterization follows the methodology prescribed by EPA (1989a), as modified by more recent information and guidance. EPA methods are, appropriately, designed to be health-protective, and tend to overestimate, rather than underestimate, risk. The risk results, however, may be overly conservative, because risk characterization involves multiplication of the conservative assumptions built into the estimation of source-term concentrations and EPCs, the exposure (intake) estimates, and the toxicity dose-response assessments.

5.1 Carcinogenic Effects of Chemicals

The risk from exposure to potential chemical carcinogens is estimated as the probability of an individual developing cancer over a lifetime, and is the ILCR. In the low-dose range, which would be expected for most environmental exposures, cancer risk is estimated from the following linear equation (EPA, 1989a):

$$ILCR = (CDI) (SF) \qquad \text{Eq. 5.1}$$

where:

- ILCR = incremental lifetime cancer risk, a unitless expression of the probability of developing cancer, adjusted for background incidence, calculated
- CDI = chronic daily intake, averaged over 70 years (mg/kg-day)
- SF = cancer slope factor (per mg/kg-day).

The CDI term in Equation 5.1 is equivalent to the "I" or "DAD" terms (intake or dose) in Equations 3.6, 3.7, 3.8, and 3.13, when these equations are evaluated for cancer intakes.

The use of Equation 5.1 assumes that chemical carcinogenesis does not exhibit a threshold, and that the dose-response relationship is linear in the low dose range. Because this equation could generate theoretical cancer risks greater than 1 for high dose levels, it is considered to be inaccurate at cancer risks greater than 1E-2. In these cases, cancer risk is estimated by the one-hit model:

$$ILCR = 1 - e^{-(CDI)(SF)} \quad \text{Eq. 5.2}$$

where:

- ILCR = incremental lifetime cancer risk, a unitless expression of the probability of developing cancer, adjusted for background incidence, calculated
- $-e^{-(CDI)(SF)}$ = the exponential of the negative of the risk calculated using Equation 5.1.

As a matter of policy, EPA (1986) considers the carcinogenic potency of simultaneous exposure to low doses of carcinogenic chemicals to be additive, regardless of the chemical's mechanisms of toxicity or sites (organs of the body) of action. Cancer risk arising from simultaneous exposure by a given pathway to multiple chemicals is estimated from the following equation:

$$ILCR_p = ILCR_{(chem\ 1)} + ILCR_{(chem\ 2)} + \dots + ILCR_{(chem\ i)} \quad \text{Eq. 5.3}$$

where:

- ILCR_p = total pathway incremental lifetime cancer risk, calculated
- ILCR(chem_i) = individual chemical cancer risk.

Cancer risk for a given receptor across pathways and across media is summed in the same manner. The sum of the ILCR summed across pathways is the total ILCR as shown in the equation below.

$$\text{Total ILCR} = \text{ILCR}(p 1) + \text{ILCR}(p 2) + \dots \text{ILCR}(p i) \quad \text{Eq. 5.4}$$

where:

Total ILCR = total incremental lifetime cancer risk across all pathways
 ILCR_{pi} = incremental lifetime cancer risks associate with pathway "I".

The total ILCR represents all additional cancer risks posed to a given receptor by contact with contaminants in site environmental media.

Total ILCRs in the range of 1E-6 to 1E-4 are regarded as acceptable (EPA, 1990); This range is hereinafter referred to as the risk management range. Risks less than this range are regarded as negligible.

5.2 Noncancer Effects of Chemicals

The hazards associated with noncancer effects of chemicals are evaluated by comparing an exposure level or intake with an RfD. The HQ, defined as the ratio of intake to RfD, is estimated as (EPA, 1989a):

$$HQ = I / RfD \quad \text{Eq. 5.5}$$

where:

HQ = hazard quotient (unitless, calculated)
 I = intake of chemical averaged over subchronic or chronic exposure period (mg/kg-day)
 RfD = reference dose (mg/kg-day).

The I term in Equation 5.5 is equivalent to the "I" or "DAD" terms (intake or dose) in Equations 3.6, 3.7, 3.8, and 3.13, when these equations are evaluated for noncancer intakes.

As shown above, both the "I" and the RfD are in units of mg/kg-day. The RfD has been developed to represent a dose rate unlikely to result in any adverse noncancer health effects, even to the most susceptible members of the population. Therefore, if the "I" is equal to or less than the RfD (i.e., $HQ \leq 1$), adverse noncancer health effects are unlikely. HQ values exceeding 1 do not indicate that noncancer hazard is likely to occur, but rather that the occurrence of an adverse noncancer health effect can not be termed "unlikely". The HQ does not define a particular risk

level, nor can it be used to infer information regarding a dose-response curve. That is, an HQ of 0.01 does not imply a 1 in 100 chance of an adverse effect, but indicates that the estimated intake is 100 times lower than the RfD. This approach is different from the probabilistic approach described in Section 5.1 to evaluate cancer risks.

In the case of simultaneous exposure of a receptor to several chemicals, an HI is calculated as the sum of the HQs by:

$$HI = I_1 / RfD_1 + I_2 / RfD_2 + \dots I_i / RfD_i \quad \text{Eq. 5.6}$$

where:

HI = hazard index (unitless, calculated)
 I_i = intake for the i^{th} toxicant
 RfD_i = reference dose for the i^{th} toxicant.

If the HI for a given pathway exceeds 1, individual HI values may be calculated for each target organ. A total HI is calculated by summing the HI values, associated by target organ(s), across exposure pathways as follows:

$$Total HI_a = HI_{p1-a} + HI_{p2-a} + \dots HI_{pi-a} \quad \text{Eq. 5.7}$$

where:

Total HI_a = total hazard index for target organ "a" (unitless, calculated)
 HI_{pi-a} = hazard index for target organ "a" via pathway "i".

5.3 Groundwater Risk Characterization Results

Risk characterization results for groundwater at each AOC and at the facility boundary will be presented in tables and discussed in text. Potential cancer (Section 5.1) and adverse noncancer effects (Section 5.2) for each receptor will be presented separately. Detailed spreadsheet calculations will be appended to the BHHRA.

5.4 Overall AOC Risk Results

Potential risks associated with exposure to site soil and, where applicable, surface water and sediment were evaluated for each of the five AOCs (IT, 2001a; 2000a,b). The summed risk estimates for the future on-site resident and future long-term, on-site worker associated with

exposure to these media will be combined with summed groundwater risk estimates for each AOC, calculated consistent with this work plan, to derive estimated overall ILCR and noncancer HI values.

5.5 Summary

Risk characterization results will be briefly summarized, with special emphasis on whether or not COPC, pathways, media, and receptors exceed the cancer risk management range (1E-6 to 1E-4) and noncancer (HI>1) human health-based criteria. This summary will include risks associated with exposure to groundwater, as well as combined risks as described in Section 5.4

6.0 Uncertainty Analysis

The primary objective of the BHHRA is to characterize and quantify potential human health risks. However, these risks are estimated using incomplete and imperfect information that introduces uncertainties at various stages of the risk assessment process. Uncertainties associated with earlier stages of the risk assessment become magnified when they are concatenated with other uncertainties in the latter stages. Reliance on a simplified numerical presentation of dose rate and risk without consideration of uncertainties, limitations, and assumptions inherent in their derivation can be misleading. For example, the calculated ILCR for a given scenario “A” may be $5E-5$ (within the risk management range) and that of scenario “B” given as $5E-4$ (exceeding the risk management range). However, if the uncertainties associated with scenario “B” span, for instance, orders of magnitude and the ILCR is regarded as biased high, it is not unlikely that scenario “A” actually presents a higher risk of developing cancer.

The chief goal of this analysis is to evaluate uncertainties and present them in context of their potential impact on the interpretation of the risk assessment results and the types of environmental management decisions that may be based on these results. The uncertainty analysis does not exhaustively describe all potential uncertainties but presents those that have the largest implications for the interpretation of the risk assessment results. This analysis also overviews the types and, as applicable, the magnitude of the uncertainties at each stage of the risk assessment. Although the BHHRA will include generic uncertainties that are common to the state of human health risk assessment practice (e.g., additivity of health effects in the risk characterization), overall, the uncertainty analysis focuses on a set of uncertainties that is peculiar to specific PBOW sites.

6.1 Types of Uncertainty

Uncertainties in risk assessment are categorized into two general types: 1) variability inherent in the (true) heterogeneity of the data set, measurement precision, and measurement accuracy; and 2) uncertainty that arises from data gaps. Estimates of the degree of variability tend to decrease as the sample size increases. This is because larger data sets are less impacted by individual samples/measurements and typically allow for greater accuracy. Uncertainty that arises from data gaps is addressed by applying models and assumptions. Models are applied because they represent a level of understanding to address certain exposure parameters that are impractical or impossible to measure (e.g., COPC concentrations in air that would result from groundwater use

that has not yet occurred—or may never occur—at the site). Assumptions represent an educated estimate to address information that is not available (e.g., additivity of carcinogens).

6.2 Sources of Uncertainty

A discussion will be provided that to describe an overview of general sources of uncertainty and focus on those most likely to affect the interpretation of the BHHRA results. This analysis will focus on groundwater risks, but the uncertainties associated with other media will also be included as they affect overall risks. These sources may include, but are not limited to, the following:

- Representativeness of samples
- Laboratory procedures and analytical methods
- Sampling methods
- Adequacy of background data set
- Comparisons to background concentrations
- Land-use and groundwater use assumptions
- Routes of exposure
- Exposure assessment values
- Exposure models
- Methods of calculating EPCs
- Toxicity values
- Form or isomer of chemical
- Interactions of multiple contaminants.

The PBOW groundwater BHHRA will identify and describe the unique set of uncertainties associated with the site. Special attention may be given to those uncertainties that are thought to have the most significant impact on risk and/or remediation decisions.

7.0 Development of Risk-Based Remediation Criteria for Groundwater

RBRCs are derived to provide support for risk management decisions. Thus, they are developed only for the chemicals of concern (COC) in media that are associated with unacceptable risk that may potentially warrant corrective action. RBRCs are site-specific concentrations that reflect the exposure and toxicity assumptions applied in the BHHRA(s). Separate sets of groundwater RBRC values would be derived for each PBOW AOC (and the site boundary wells) at which COCs are identified. The development of groundwater RBRCs would involve a balance of cancer risk and noncancer hazard estimates separately for each site, including those associated with media other than groundwater. The potential effect of remedial activities already accomplished to date would also be considered on potential future site risks. Should groundwater COCs be identified at any AOCs, or at the facility boundary, the development of groundwater RBRCs would be an iterative process with on-going discussion between OEPA and the USACE.

8.0 Summary/Conclusions

The BHHRA will include a brief summary/conclusion section that will summarize the results of the risk characterization, with a sufficient level of elucidation addressing the effects that uncertainties may have on these results. Planned and implemented remedial actions will also be discussed as appropriate. The goal is to present the BHHRA in a context that is most appropriate for the support of environmental decision-making.

9.0 References

California Environmental Protection Agency, 2005, *Toxicity Criteria Database*, Office of Environmental Health Hazard Assessment, Sacramento, California, <http://www.oehha.co.gov/risk/ChemicalDB/index.asp>.

City-data.com, 2004, on-line data search for Sandusky, Ohio, performed November 11, 2004, <http://www.city-data.com/city/Sandusky-South-Ohio.html>.

Dames and Moore, Inc. (D&M), 1997, *TNT Areas Site Investigation Final Report, Plum Brook Ordnance Works, Plum Brook Station/NASA, Sandusky, Ohio*, prepared for U.S. Army Corps of Engineers, Nashville District/Huntington District, April.

Gilbert, R. O., 1987, *Statistical Methods for Environmental Pollution Monitoring*, New York, New York: Van Nostrand Reinhold.

Hardin, J. W., and R. O. Gilbert, 1993, *Statistical Tests for Detecting Soil Contamination Greater than Background*, PNL-8989/UC-630, Pacific Northwest Laboratory, Richland, Washington, December.

International Consultants Incorporated, 1995, *Site Management Plan, Part B Areas of Concern, Plum Brook Ordnance Works, Sandusky, Ohio*, September.

IT Corporation (IT), 2001a, *TNT Areas A and C Remedial Investigation, Volume II – Human Health Risk Assessment, Final, Former Plum Book Ordnance Works, Sandusky, Ohio*, November.

IT Corporation (IT), 2001b, *TNT Areas A and C Remedial Investigation, Volume I – Report of Findings, Final, Former Plum Book Ordnance Works, Sandusky, Ohio*, November.

IT Corporation (IT), 2000a, *Risk Assessment and Direct-Push Investigation of Red Water Pond Areas, Final, Former Plum Book Ordnance Works, Sandusky, Ohio*, August.

IT Corporation (IT), 2000b, *Final TNT Area B Remedial Investigation, Volume II – Baseline Human Health Risk Assessment and Volume III – Ecological Risk Assessment, Final, Former Plum Book Ordnance Works, Sandusky, Ohio*, August.

IT Corporation (IT), 1999a, *Baseline Human Health Risk Assessment and Ecological Risk Assessment Work Plans, TNT Area B, Final, Former Plum Brook Ordnance Works, Sandusky, Ohio*, May.

IT Corporation (IT), 1999b, *Summary Report, Site-Wide Groundwater Monitoring (1997-1998), Final, Former Plum Brook Ordnance Works, Sandusky, Ohio*, June.

IT Corporation (IT), 1998, ***Baseline Human Health Risk Assessment and Ecological Risk Assessment Work Plans, Red Water Ponds Areas, Final, Former Plum Brook Ordnance Works, Sandusky, Ohio***, September.

IT Corporation (IT), 1997, ***Site-Wide Groundwater Investigation Report, Plum Brook Ordnance Works, Sandusky, Ohio***, September.

Land, C.E., 1975, "Tables of Confidence Limits for Linear Functions of the Normal Mean and Variance," in ***Selected Tables in Mathematical Statistics***, Vol. III, American Mathematical Society, Providence, Rhode Island.

National Oceanic and Atmospheric Administration, 1990, ***Comparative Climatic Data for the United States through 1989***, National Climatic Data Center, Asheville, North Carolina.

Ohio Environmental Protection Agency (OEPA), 2004, e-mail correspondence from L. Moore (OEPA Risk Assessor) to L. Long (USACE Risk Assessor), December 15.

Ohio Environmental Protection Agency (OEPA), 1993, ***Closure Plan Review Guidance for RCRA Facilities***, Interim Final, OEPA Division of Hazardous Waste Management, September 1.

Science Applications International Corporation (SAIC), 1991, ***NASA Plum Brook Station, Preliminary Assessment***, Volume I, Sandusky, Ohio, June.

Shaw Environmental, Inc. (Shaw), 2004, ***2004 Groundwater Data Summary and Evaluation Report, Draft, Former Plum Brook Ordnance Works, Sandusky, Ohio***, December.

The Weather Channel, 2004, on-line data search for weather averages and records for Sandusky, Ohio, performed November 11, 2004, <<http://www.weather.com>>.

U.S. Army Corps of Engineers (USACE), 2001, ***Scope of Work, Phase II Groundwater Remedial Investigation (RI), TNT and Red Water Ponds Area, Former Plum Brook Ordnance Works, Sandusky, Ohio***, December 10.

U.S. Army Corps of Engineers (USACE), 1999, ***Risk Assessment Handbook, Volume I: Human Health Evaluation***, Engineer Manual EM 200-1-4.

U.S. Environmental Protection Agency (EPA), 2005, ***Integrated Risk Information System (IRIS)***, National Center for Environmental Assessment, Cincinnati, Ohio, <<http://www.epa.gov/iris/index.html>>.

U.S. Environmental Protection Agency (EPA), 2004a, ***Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual [Part E - Supplemental Guidance for Dermal Risk Assessment]***, Final, Office of Superfund Remediation and Technology Innovation, Washington, D.C., EPA/540/R-99/005, July.

U.S. Environmental Protection Agency (EPA), 2004b, **Region 9 Preliminary Remediation Goals (PRG) Table**, Region 9, San Francisco, California, October, <<http://www.epa.gov/region09/waste/sfund/prg/files/prgtable.pdf>>.

U.S. Environmental Protection Agency (EPA), 2004c, **User's Guide and Background Technical Document for Region 9 Preliminary Remediation Goals (PRG) Table**, Region 9, San Francisco, California, October, <<http://www.epa.gov/region09/waste/sfund/prg/files/04usersguide.pdf>>.

U.S. Environmental Protection Agency (EPA), 2003a, **Updated Dermal Exposure Assessment Guidance**, EPA Region 3, Philadelphia, Pennsylvania, June.

U.S. Environmental Protection Agency (EPA), 2003b, **Human Health Toxicity Values in Superfund Risk Assessments**, Office of Solid Waste and Emergency Response, Washington, D.C., OSWER Directive 9285.7-53, December.

U.S. Environmental Protection Agency (EPA), 1997a, **Exposure Factors Handbook**, Office of Research and Development, National Center for Environmental Assessment, Washington, DC, EPA/600/P-95/002F, August.

U.S. Environmental Protection Agency (EPA), 1997b, **The Lognormal Distribution in Environmental Applications**, Technology Support Center Issue Paper, EPA/600/R-97/006, December.

U.S. Environmental Protection Agency (EPA), 1997c, **Health Effects Assessment Summary Tables, FY 1997 Update**, Office of Solid Waste and Emergency Response, 9200.6-303 (97-1), EPA-540-R-97-036, NTIS No. PB97-921197.

U.S. Environmental Protection Agency (EPA), 1992a, **Supplemental Guidance to RAGS: Calculating the Concentration Term**, Office of Solid Waste and Emergency Response, Washington, D.C., Publication 9285.7-081.

U.S. Environmental Protection Agency (EPA), 1992b, **Dermal Exposure Assessment: Principles and Applications**, Interim Report, Office of Research and Development, Washington, DC, EPA/600/8-91/011B, including Supplemental Guidance dated August 18, 1992.

U.S. Environmental Protection Agency (EPA), 1992c, "Guidance on Risk Characterization for Risk Managers and Risk Assessors," Memorandum from F. Henry Habicht II, Deputy Administrator, to Assistant Administrators, Regional Administrators, February 26.

U.S. Environmental Protection Agency (EPA), 1992d, **Statistical Training Course for Groundwater Monitoring Data Analysis**, Office of Solid Waste, EPA/530/R-93/003.

U.S. Environmental Protection Agency (EPA), 1991a, **Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual Supplemental Guidance, Standard**

Default Exposure Factors, Interim Final, Office of Solid Waste and Emergency Response, OSWER Directive: 9285.6-03.

U.S. Environmental Protection Agency (EPA), 1991b, ***Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual Part B – Development of Risk-Based Preliminary Remediation Goals***, Interim, Office of Emergency and Remedial Response, Washington, D.C., EPA/540/R-92/003, December.

U.S. Environmental Protection Agency (EPA), 1990, 40 CFR Part 300, "National Oil and Hazardous Substances Pollution Contingency Plan; Final Rule," ***Federal Register*** 55 (46): 8666-8865.

U.S. Environmental Protection Agency (EPA), 1989a, ***Risk Assessment Guidance for Superfund***, Volume I, Human Health Evaluation Manual (Part A), Interim Final, Office of Emergency and Remedial Response, Washington, D.C., EPA/540/1-89/002.

U.S. Environmental Protection Agency (EPA), 1989b, ***General Quantitative Risk Assessment Guidelines for Noncancer Health Effects***, Prepared by the Office of Health and Environmental Assessment, Cincinnati, OH for the Risk Assessment Forum, ECAO-CIN-538.

U.S. Environmental Protection Agency (EPA), 1986, ***Guidelines for Carcinogen Risk Assessment***," ***Federal Register***, 51(185): 33992-34003.

U.S. Environmental Protection Agency (EPA), 1990, ***National Oil and Hazardous Substances Pollution Contingency Plan***, 40 CFR Part 300.430.

U.S. Geological Survey, 1992, ***Hydraulic Properties of Three Types of Glacial Deposits in Ohio***, Water-Resources Investigation Report 92-4135.

TABLES

Table 2-1

**Sampling Locations to be Used in the
Baseline Human Health Risk Assessment of Groundwater
Former Plum Brook Ordnance Works
Sandusky, Ohio**

Site Area	Overburden Sampling Location	Bedrock Sampling Location
TNT Area A	TNTA-MW10 TNTA-MW11 MK-MW22 MK-MW23 MK-MW24 TNTA-GW01 through TNTA-GW07 ^a TNTA-GW10 ^a	PB-BED-MW18 TNTA-BEDGW-001
TNT Area B	MK-MW17	TNT-BEDGW-001 TNT-BEDGW-003 TNT-BEDGW-004
TNT Area C	TNTC-MW03 TNTC-MW04 TNTC-MW05 TNTC-MW06 IT-MW09 TNTC-GW02 through TNTC-GW06 ^a TNTC-GW08 through TNTC-GW10 ^a	TNTC-BEDGW-001 BED-MW13
Pentolite Road Red Water Pond Area	IT-MW05 PR-MW07 PR-MW08 PR-MW09 PRRP-DP01 through PRRP-DP20 ^a	BED-MW15 BED-MW23
West Area Red Water Ponds Area	WA-MW01 WA-MW02 IT-MW02 IT-MW10 WARP-DP01 WARP-DP02 WARP-DP04 WARP-DP06 through WARP-DP09 ^a WARP-DP11 through WARP-DP13 ^a WARP-DP15 through WARP-DP17 ^a WARP-DP19	BED-MW14
Downgradient Boundary Wells	NA ^b	BED-MW17 BED-MW19 BED-MW22 BED-MW24 BED-MW27

^a Sample collected using direct-push method.

^b "NA" indicates "not applicable." Some overburden groundwater samples were collected near the facility boundary, but these are not regarded as representing conditions downgradient because groundwater within the overburden is highly discontinuous.

Table 3-1

**Variables Used to Estimate Potential Chemical Intake
and Contact Rates from Groundwater
Plum Brook Ordnance Works, Sandusky, Ohio**

(Page 1 of 2)

Pathway Variable	On-site Worker	Resident
General Variables		
Exposure duration (ED), years	25 ^a	Child: 6 ^b Adult: 24 ^b
Body weight (BW), kg	70 ^a	Child: 15 ^b Adult: 70 ^a
Averaging time, noncancer (AT), days ^c	9125	Child: 2190 Adult: 8760
Averaging time, cancer (AT), days ^c	25550	25550
Inhalation of VOCs from Groundwater		
Exposure time (ET), hours/day	NA	24 ^d
Inhalation rate (IR _a), m ³ /hour	NA	Adult: 0.833 ^b Child: 0.416 ^b
Exposure frequency (EF), days/year	250 ^a	350 ^a
Drinking Water Ingestion of Groundwater		
Fraction exposed to contaminated medium (F _{lgw}), unitless	1 ^f	1 ^f
Drinking water ingestion rate (IR _{gw}), L/day	1 ^a	Child: 1 ^b Adult: 2 ^a
Exposure frequency (EF), days/year	250 ^a	350 ^a
Dermal Contact with Groundwater		
Fraction exposed to contaminated medium (F _{lgw}), unitless	1 ^e	1 ^e
Body surface area exposed to water (S _{agw}), cm ²	3300 ^g	Child: 6600 ^f Adult: 20000 ^f
Permeability coefficient (PC), cm/hour	csv	csv
Exposure time (ET _{gw}), hours/day	1 ^f	Child: 0.333 ^g Adult: 0.2 ^d
Exposure frequency (EF), days/year	250 ^a	350 ^a

cm - Centimeter.

cm² - Square centimeter.

csv - Chemical-specific value.

kg - Kilogram.

L - Liters.

m³ - Cubic meters.

NA - Not applicable to this receptor.

VOC - Volatile organic compound.

Table 3-1

Variables Used to Estimate Potential Chemical Intake and Contact Rates from Groundwater Plum Brook Ordnance Works, Sandusky, Ohio

(Page 2 of 2)

^aU.S. Environmental Protection Agency (EPA), 1991, *Risk Assessment Guidance for Superfund Volume 1: Human Health Evaluation Manual Supplemental Guidance, Standard Default Exposure Factors*, Interim Final, Office of Solid Waste and Emergency Response, OSWER Directive: 9285.603.

^bU.S. Environmental Protection Agency (EPA), 2004, *User's Guide and Background Technical Document for EPA Region 9 Preliminary Remediation Goals (PRG) Table*, Region 9, San Francisco, California, October.

^cCalculated as the product of ED (years) x 365 days/year.

^dThe *Exposure Factors Handbook* (see reference g) indicates that the 90th percentile for the amount of time spent at a residence is more than 23 hours per day.

^eAssumed; see text.

^fU.S. Environmental Protection Agency (EPA), 2004, *Risk Assessment Guidance for Superfund Volume 1: Human Health Evaluation Manual (Part E - Supplemental Guidance for Dermal Risk Assessment)*, Final, Office of Superfund Remediation and Technology Innovation, Washington, D.C., July, EPA/540/R-99/005.

^gU.S. Environmental Protection Agency, (EPA), 1997, *Exposure Factors Handbook*, Final, National Center for Environmental Assessment, Washington, D.C., EPA/600/P-95/002Fa, August.

FIGURES

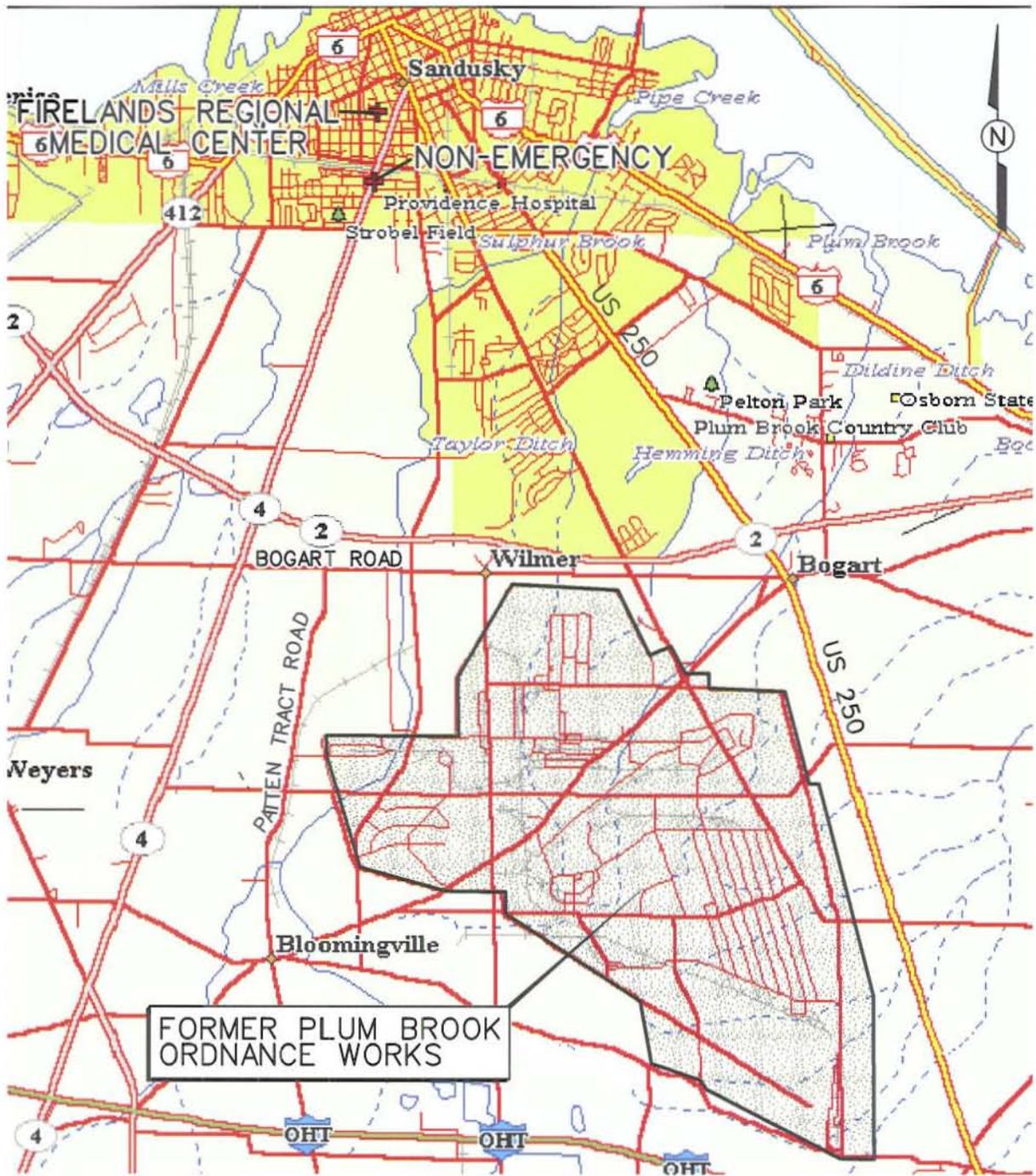
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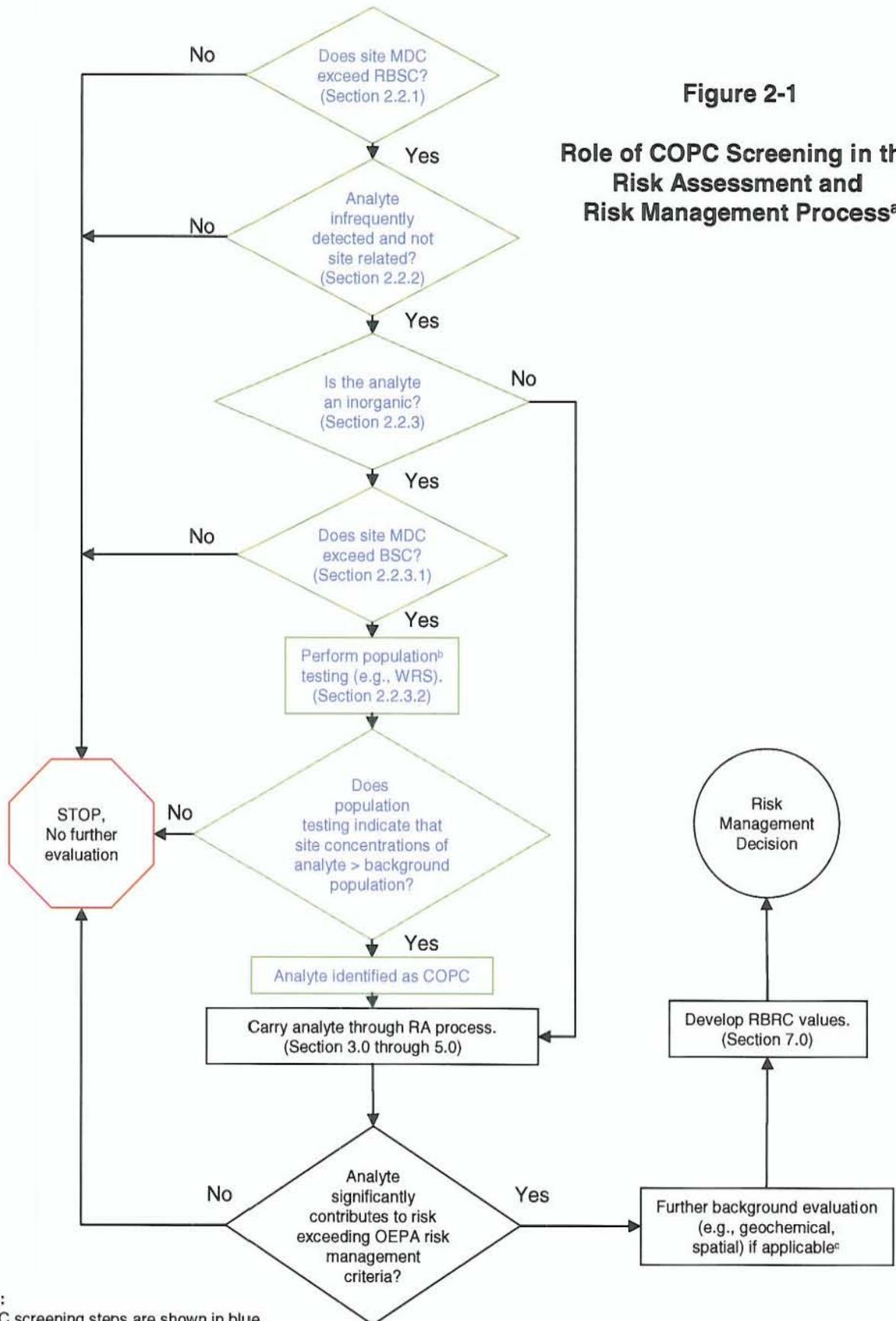
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FIGURE 1-1
 VICINITY MAP

BASELINE HUMAN HEALTH RISK ASSESSMENT
 OF GROUNDWATER WORK PLAN
 FORMER PLUM BROOK ORDNANCE WORKS
 NASA PLUM BROOK STATION
 SANDUSKY, OHIO

Figure 2-1

Role of COPC Screening in the Risk Assessment and Risk Management Process^a



Notes:

^a COPC screening steps are shown in blue.

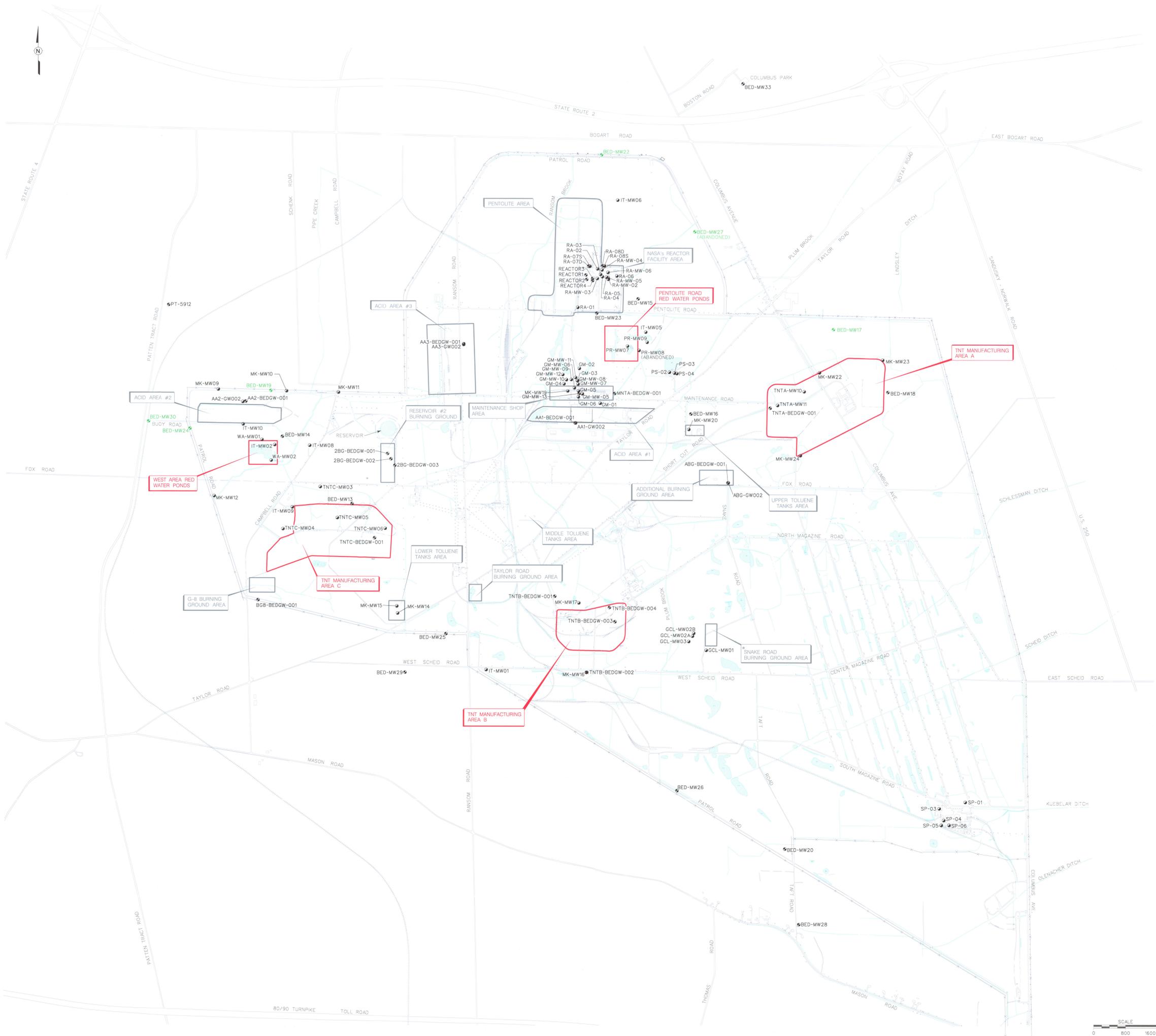
^b A judgment may be made at this step to forego or modify population testing if the site data is clearly greater than background and/or individual exceedances suggest the presence of a hot spot. In such cases, the analyte would be carried into the risk assessment process.

^c Refer to Appendix L of the 2004 Groundwater Data Summary and Evaluation Report (Shaw, 2004).

BSC - Background screening concentration. COPC - Chemical of potential concern. MDC - Maximum detected concentration.
 OEPA - Ohio Environmental Protection Agency. RA - Risk assessment. RBC - Risk-based remediation criterion.
 RBSC - Risk-based screening concentration. WRS - Wilcoxon rank sum (test).



- LEGEND:**
- OVERBURDEN MONITORING WELL LOCATION
 - BEDROCK MONITORING WELL LOCATION
 - DOWNGRADIENT BEDROCK MONITORING WELL THAT WILL BE USED TO EVALUATE OFF-SITE EXPOSURE/RISKS
 - BOUNDARY OF AREA OF CONCERN TO BE EVALUATED FOR GROUNDWATER RISKS
 - POND
 - CREEK, DITCH, CONVEYANCE
 - RAILROAD
 - ROAD
 - FENCE



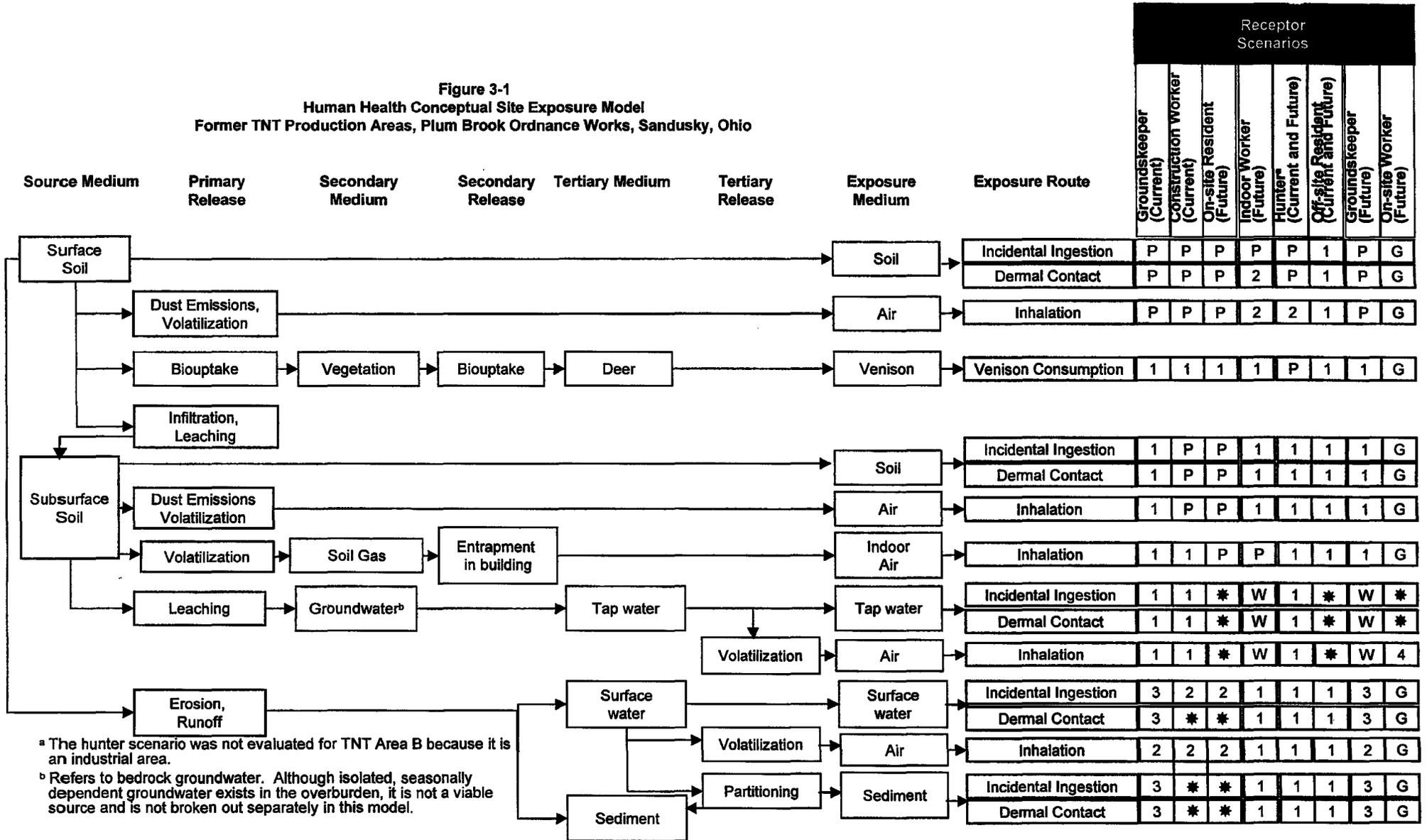
- NOTES:**
1. SNAKE ROAD BURNING GROUND AREA WAS ALSO REFERRED TO AS "SNAKE ROAD BURN PITT", SCHEID ROAD BURNING GROUNDS*, AND "DISPOSAL AREA THREE".
 2. AREAS OF CONCERN NOT SHOWN ARE:
RESERVOIR #1
WASTE WATER DISPOSAL PLANT #1
WASTE WATER DISPOSAL PLANT #2
POWER HOUSE #2 ASH PITT
 3. REACTOR FACILITY CONSTRUCTED BY NASA POST MW11 AND IS IDENTIFIED FOR LOCATION PURPOSES ONLY.

STARTING DATE	INITIATOR	/CND	DRAMA	CHD	PROJECT
1/23/04	T. SAK	T. SAKS	J. BOYAK	WNG	5309W11
Shaw Environmental, Inc.					
BASELINE HUMAN HEALTH RISK ASSESSMENT OF GROUNDWATER WORK PLAN 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	833886	833886ES.005			



A
B
C
D
E
F
G
H
I
J
K
L
M

Figure 3-1
Human Health Conceptual Site Exposure Model
Former TNT Production Areas, Plum Brook Ordnance Works, Sandusky, Ohio



^a The hunter scenario was not evaluated for TNT Area B because it is an industrial area.

^b Refers to bedrock groundwater. Although isolated, seasonally dependent groundwater exists in the overburden, it is not a viable source and is not broken out separately in this model.

* = Complete exposure route to be quantified in the groundwater baseline human health risk assessment (BHRA).

1 = There is no plausible pathway for exposure to this medium.

2 = Although theoretically complete, this pathway is not quantified as explained in text of the previous BHHRAs.

3 = Contact with this medium, although plausible, is not part of this receptor's normal or expected activities therefore, contact would be sporadic and is not quantified.

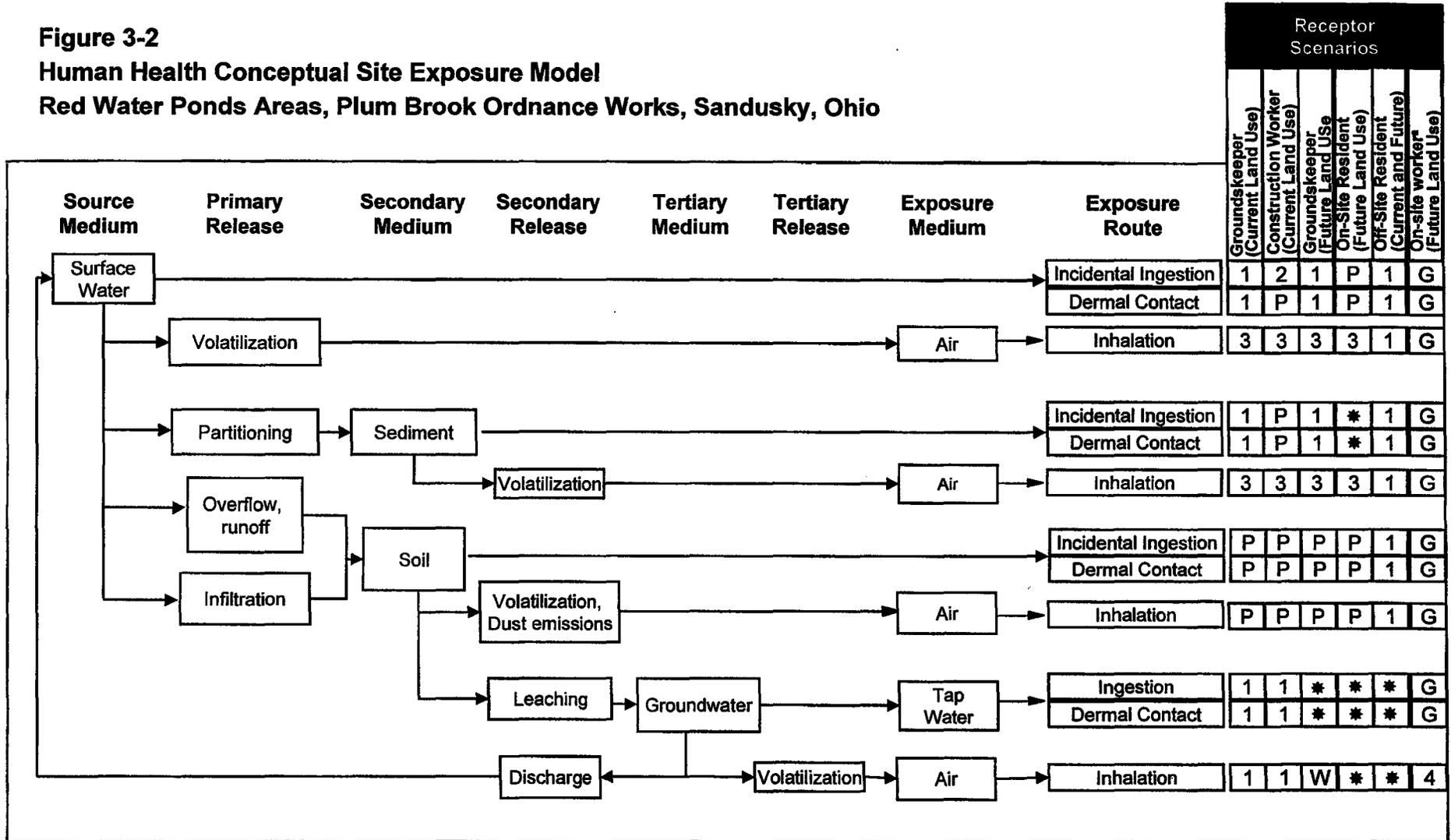
4 = Although theoretically complete, large dilution factor of ambient air obviates the need to quantify this pathway for an outdoor worker. Exposure to future indoor worker using site groundwater would not be quantifiable but would likely be insignificant compared to other pathways.

P = Complete exposure pathway evaluated in the previous BHHRAs for the former TNT production areas.

G = On-site worker to be evaluated for groundwater only. Risk results for this receptor will be combined with those from previous BHHRAs to determine overall risks to the future indoor worker and future groundskeeper.

W = Groundwater exposure/risks evaluated as future on-site worker (see note for "G").

Figure 3-2
Human Health Conceptual Site Exposure Model
Red Water Ponds Areas, Plum Brook Ordnance Works, Sandusky, Ohio



- 1 = Incomplete exposure pathway.
- 2 = Incidental ingestion of surface water is expected to be insignificant compared with dermal exposure. Pathway not quantitatively evaluated.
- 3 = Although theoretically complete, large dilution factor of ambient air obviates the need to quantify this pathway.
- 4 = Although theoretically complete, large dilution factor of ambient air obviates the need to quantify this pathway for an outdoor worker. Exposure to a future indoor worker using site groundwater would not be quantifiable but would likely be insignificant compared to other pathways.
- * = Complete exposure pathway to be evaluated in the groundwater baseline human health risk assessment (BHHRA).
- P = Complete exposure pathways evaluated previously in the Red Water Ponds Areas BHHRA.
- G = On-site worker to be evaluated for groundwater only. Risk results for the receptor will be combined with those for the future groundskeeper from the previous BHHRAs.
- W = Groundwater exposure/risks evaluated as future on-site worker (see note for "G").

RESPONSE TO COMMENTS

Responses to Comments
Draft Baseline Human Health Risk Assessment
of Groundwater Work Plan
Plum Brook Ordnance Works, Sandusky, Ohio,
November 30, 2004

Review Comments by US Army Center for Health Promotion and Preventive Medicine (USACHPPM)

Reviewer: Larry Tannenbaum, Environmental Health Risk Assessment Program

Comment 1: **Page 1-6, Section 1.5, Organization of the BHHRA.**
Comment The bulleted “Toxicity Assessment” paragraph does not appear to be complete. The paragraph discusses “adverse noncancer health effects” only, and does not mention cancer assessments.
Recommendation: In the revised work plan, please expand the identified paragraph such that the cancer-causing properties of contaminants are also briefly discussed.

Response 1: The first sentence of the bulleted “Toxicity Assessment” will be revised to more accurately reflect the purpose and contents of the toxicity assessment section to state: “Describes the potential for cancer and/or noncancer human health effects, provides an estimate of the quantitative relationship between the magnitude of dose or contact rate and the probability and/or severity of adverse effects, identifies the toxicity values that are used in the BHHRA, and describes the development of dermal toxicity values.”

Comment 2: **Page 2-4, Section 2.2.1, Risk-Based Screening**
Comment: The first sentence of the page’s second full paragraph should be modified for clarity.
Recommendation: Please delete the first usage of “either” in the sentence.

Response 2: The first usage of “either” will be deleted as recommended.

Comment 3: **Page 3-2, Section 3.1, Conceptual Site Exposure Model**
Comment: The text notes that Figures 3-1 and 3-2 reflect plausible scenarios. Are both on-site and off-site ground-water residents reasonable (plausible) to consider, though? Many times such exposures are included as fixtures of risk assessments without supportive documentation provided. Also, the Section’s last sentence may not be accurate. The “G” that appears in the “on-site future worker” column of Figure 3-2, indicates that the on-site worker is also to be evaluated for ground-water exposure.

Recommendation: In the revised work plan, please consider having the text specifically support the selection of residents as reasonable ground-water users to evaluate. A brief treatment would include the quality and anticipated yield of ground water, and the economic feasibility of tapping into the ground water as a drinking water source. Please address the point concerning the on-site worker as a ground-water user, in light of the text of page 3-2 that limits ground-water use to residents.

Response 3: It is the desire of the National Aeronautics and Space Administration (NASA) to release the property for unrestricted use; a statement to this effect will be added to the last paragraph of Section 1.3. Although most of the residents in the area use municipal water, there are numerous private wells in the area (refer to Section 1.3). Clearly, off-site resident use of groundwater would seem plausible. Assuming unrestricted future land use, the development of groundwater for residential (or worker) use is likewise regarded as plausible. Text consistent with the following will be added to the end of Section 3.1: “Although a majority of the residents are serviced by municipal water (from surface water sources) there are numerous private groundwater wells in the vicinity, including eight within 1 mile of the facility boundary. Also, based on monitoring wells and a nearby off-site private well sampled as part of the site groundwater investigation, the bedrock units produce adequate quantity. Although natural hydrocarbons are known to be present within the bedrock limestone and shale formations, groundwater underlying the site cannot be summarily excluded for consideration as a tap water source based on natural water quality parameters. Therefore, given the presence of numerous off-site wells and the assumption of unrestricted future land use on site, the development of groundwater for off-site or on-site residential (or on-site worker) use as tap water is regarded as plausible.”

The last sentence of the section will be rewritten as follows to clarify its intended meaning: “For the current and future off-site resident, only groundwater exposure is evaluated (refer to Figures 3-1 and 3-2).”

Comment 4: **Pages 3-7 to 3-8, Section 3.1.3.2, Resident**
Comment: The text first notes (bottom of page 3-7) that because children tend to bathe rather than shower, only an adult resident will be evaluated for inhalation of volatilized organics compounds. Why then is the assumed child’s bathing duration discussed in the first full paragraph of page 3-8?
Recommendation: Please remove the text about the child’s bathing exposure duration.

Response 4: The length of the child’s bathing duration affects the level of dermal exposure to contaminants in water (refer to Equation 3.14 of the draft work plan) and may affect the selection of the equation to estimate dermal exposure of contaminants in water (refer to last paragraph on page 3-16 of the draft

beginning with “ K_p for organic chemicals varies ...”). Therefore, the reference to the child’s bathing duration will be left in the text.

The reviewer should be advised that the showering model will not be used in the baseline human health risk assessments (BHHRA) for groundwater and will not be included in the final work plan. Prior to submittal of the draft Baseline Human Health Risk Assessment for Groundwater Work Plan, the U.S. Army Corps of Engineers contacted the Ohio Environmental Protection Agency (OEPA) to: 1) ask whether the OEPA had a preference as to what model would be used to evaluate exposure to volatile chemicals in tap water via inhalation, and 2) provide a recommendation for the Foster-Chrostowski (1987) showering model that is described in the draft work plan. The OEPA risk assessor replied via email (OEPA, 2004), after submittal of the draft work plan, that the Agency programmatically uses the whole-house screening model described in the Human Health Evaluation Manual Volume 1, Part B (EPA, 1991), though noting that that the whole-house model has far greater associated uncertainties. Therefore, the final work plan will be revised to delete the description of the Foster-Chrostowski model and add a description for the whole-house model and associated model parameters. Any relevant uncertainties would be discussed in the uncertainty section of the individual groundwater BHHRAs.

Comment 5: **Page 7-1, Section 7.0, Development of Risk-Based Remediation Goals**
Comment: The text of this Section suggests that risk-based remediation criteria (RBRCs) are to be developed as a matter of course. RBRCs though, are premature at this stage because the evaluated exposures might not show unacceptable risk.
Recommendation: Please consider revising this Section to say that in the event the risk assessment indicates unacceptable risk from ground-water exposure, RBRCs will then be developed.

Response 5: Based on this comment, Chapter 7.0 will be revised consistent with the following text: “Risk-based remediation criteria (RBRC) are derived to provide support for risk management decisions. Thus, they are developed only for the chemicals of concern (COC) in media that are associated with unacceptable risk and/or may potentially warrant corrective action. RBRCs are site-specific concentrations that reflect the exposure and toxicity assumptions applied in the BHHRA(s). Separate sets of groundwater RBRC values would be derived for each PBOW AOC (and the site boundary wells) at which COCs are identified. The development of groundwater RBRCs would involve a balance of cancer risk and noncancer hazard estimates separately for each site, including those associated with media other than groundwater. The potential effect of remedial activities already accomplished to date would also be considered on potential future site risks. Should groundwater COCs be identified at any AOCs, or at the facility

boundary, the development of groundwater RBRCs would be an iterative process with on-going discussion between OEPA and the USACE.”

Review Comments by U.S. Army Corps of Engineers (USACE), Huntington District

Reviewer: Erich D. Guy, Ph.D., Environmental & Remediation Section

Comment 1: Section 1.0, third paragraph, last sentence: Remove “respectively” and reverse the order of Nashville and Huntington Districts; note Huntington has project management responsibilities and Nashville is technically overseeing this work.

Response 1: The text will be revised accordingly.

Comment 2: Section 1.2, TNTA subsection, second sentence: change “1 through 5” to “1 through 4.”

Response 2: The text will be revised accordingly.

Comment 3: Section 1.2, TNTB subsection, second sentence: change “6, 7, and 8” to “5, 6, and 7.”

Response 3: The text will be revised accordingly.

Comment 4: Section 1.2, TNTC subsection, second sentence: change “9 through 12” to “8 through 12.”

Response 4: The text will be revised accordingly.

Comment 5: Section 1.2, PRRWP Area subsection: In the first sentence a 2-acre area is referred to, but the size of this box is actually about 15 acres on Figure 1-2. Also note in this section that PRRWP received waste water from TNTB (see sect. 3.1.2. text of BHHRA draft). In the last sentence of this section change “in” to “is.”

Response 5: The text will be revised to indicate that the PRRWP Area shown on Figure 1-2 includes areas outside of the 2-acre pond footprint that were suspected as being impacted by site activities. Also, TNTB will be added as a source of waste water , and the typographical error that the reviewer identified in the last sentence will be corrected.

Comment 6: Section 2.2.1, third paragraph, second sentence: it’s stated that a multiplication factor of 0.1 will be used to adjust the noncancer values listed in the PRG tables. It makes sense to do this, but can the justification for using 0.1 be stated here (is this based on some guidance

or practical experience?), e.g., why aren't we using 0.5 or 0.01 to adjust values instead?

Response 6: As stated in the second sentence of this paragraph, noncancer values are multiplied by a factor of 0.1 to provide additional protection for simultaneous exposure to multiple chemicals. The use of a factor of 0.1 is provided as guidance by EPA Region 4 (EPA, 1995) and is suggested by EPA Region 3 (EPA, 2004a) and EPA Region 9 (EPA, 2004b). The use of a factor of 0.1 is regarded as a reasonable value for screening, given that the number of nitroaromatics in groundwater should not greatly exceed 10 (and may be less than 10); note that if the maximum detected concentrations of each of the nitroaromatics (whose effects are regarded as additive) were each at the 0.1X PRG value, adverse noncancer human health effects would be unlikely. Thus, a factor of 0.1 would be both health-protective and reasonable for screening.

The EPA Region 9 reference will be added to the end of this sentence.

Comment 7: Section 2.2.3, first sentence: remove "at."

Response 7: The typographical error will be corrected.

Comment 8: Section 3.1.1, Geology subsection: when referring to naturally occurring petroleum-derived hydrocarbons and hydrogen sulfide, cite the 9th Quarterly (March 2004) Background Groundwater Report (Shaw, 2004) which contains research documenting/supporting natural occurrences in the Delaware ls.

Response 8: The Draft 2004 Data Summary and Evaluation Report, which includes essentially the same information as the 9th Quarterly Background Groundwater Report with respect to naturally occurring petroleum, will be cited at the end of this sentence.

Comment 9: Section 3.1.3, second bullet: refer to Figure 1-2 when mentioning five boundary wells. Also, can a short statement be provided to briefly explain why other downgradient/boundary wells plotted in the figure weren't included in the evaluation?

Response 9: Figure 1-2 will be referenced in the second bullet of Section 3.1.3.2, just after the first mention of "boundary wells." According to the scope of work, risks are to be evaluated at the downgradient facility boundary as a worst-case for off-site groundwater use. The facility boundary is represented by five wells (BED-MW17, BED-MW19, BED-MW22, BED-MW24, and BED-MW27). Three additional off-site downgradient bedrock wells (PT-5912, BED-MW30, and BED-MW33) were used to evaluate extent of contamination. Wells PT-5912 and BED-MW33 are approximately 0.5 mile and 0.7 mile, respectively, downgradient from the boundary. No nitroaromatics were detected in wells

PT-5912 or BED-MW33, indicating that groundwater in the vicinity of these wells has not been impacted by site activities.

Very low concentrations of 2-nitrotoluene (0.16J µg/L) and 4-nitrotoluene (0.23 µg/L) were detected in one of the samples from well BED-MW30. This well is approximately 1,000 feet downgradient to the west of boundary well MW-24 and 2,600 feet downgradient from the West Area Red Water Pond (WARWP) Area. Neither 2-nitrotoluene nor 4-nitrotoluene were detected in any WARWP Area well, and neither compound was detected in boundary well BED-MW24. Therefore, the low concentrations reported in one of the samples collected from BED-MW30 may not be related to the site. However, it was decided that because the highest 4-nitrotoluene concentration among the downgradient wells was found in BED-GW30, this well would be evaluated in the BHHRA. The text will be revised to include BED-GW30, along with the five boundary wells, to evaluate off-site conditions.

Review Comments by U.S. Army Corps of Engineers HTRW Center of Expertise

Reviewer: Terry L. Walker, Risk Assessor

Comment 1: Section 2.3, page 2-7. The logic for not evaluating overburden groundwater as tap water is understood. There is question, however, relative to this perched groundwater to be in connection with the drinking water aquifer. Consideration should be given to the potential for migration of the perched water into the lower systems via modeling, if concentrations are of adequate magnitude. The discussion of the Red Water Ponds (Section 3.1.2, page 3-5) indicates that leaching may be an important mechanism for transport of contaminants.

Response 1: Modeling is being performed for overburden-to-bedrock groundwater impact. Modeling was mentioned (but with insufficient detail) in the third bulleted item in Section 3.1.3.2. The text will be revised to include a sentence in Section 1.3 clearly stating that perched zone-to-bedrock modeling is being performed to determine the potential impact that nitroaromatics found in perched groundwater may have on future concentrations in bedrock groundwater. Also, a similar statement will be added to the end of Section 3.1.3.1, identifying 2,4-dinitrotoluene, 2,6-dinitrotoluene, and 2,4,6-trinitrotoluene as the contaminants for which modeled concentrations will be evaluated under a future use scenario. As stated in the third bullet in Section 3.1.3.2, these concentrations will be discussed, as appropriate, in the uncertainties analysis.

Comment 2: Section 3.1.3.2, first complete paragraph, page 3-7. In the second sentence, please move “(25,550 days)” immediately after “lifetime.”

Response 2: It is assumed that the reviewer intended to state that “(25,550 days)” should be moved immediately after “70 years,” as it already appears after “lifetime.” This change will be made to the text.

Comment 3: **Section 4.5, page 4-6. In 2003, the USEPA published the memorandum, *Human Health Toxicity Values in Superfund Risk Assessments* (OSWER Directive 9285.7-53, December 5, 2003), which revised the established hierarchy of human health toxicity values, and should be utilized for CERCLA risk assessments. This guidance identifies three tiers of preferred toxicity values:**
Tier 1 values are those found in USEPA’s IRIS database.
Tier 2 values are the USEPA’s Provisional Peer Reviewed Toxicity Values (PPRTVs). The PPRTVs are developed by the Office of Research and Development (ORD), the National Center for Environmental Assessment (NCEA), and the Superfund Health Risk Technical Support Center on a chemical-specific basis when requested by the Superfund program. The PPRTVs were available on the USEPA’s external web site, but recently have been removed from public access. As the PPRTVs constitute the second tier of approved values, the HTRW CX expects that USEPA will somehow provide access to the values for use outside of their agency.
Tier 3, Other Toxicity Values, are additional EPA and non-EPA sources of toxicity information. As stated in the OSWER directive, “priority should be given to those sources of information that are the most current, the basis for which is transparent and publicly available, and which have been peer reviewed.” Two common examples of Tier 3 values are the USEPA’s Health Effects Assessment Summary Tables (HEAST) and the California EPA (CalEPA) Office of Environmental Health Hazard Assessment (OEHHA) Toxicity Criteria Database.

Response 3: The OSWER Directive will be referenced, and the three tiers provided by the reviewer will be incorporated in the final work plan.

References

Foster, S. A. and P. C. Chrostowski, 1987, "Inhalation Exposures to Volatile Organic Contaminants in the Shower," Presentation at the *80th Annual Meeting of the Air Pollution Control Association*, June 21-28.

Ohio Environmental Protection Agency (OEPA), 2004, email correspondence from L. Moore (OEPA Risk Assessor) to L. Long (USACE Risk Assessor), December 15.

U.S. Environmental Protection Agency (EPA), 2004a, *Risk-Based Concentration Table*, memorandum from Jennifer Hubbard (Region 3 Toxicologist) to RBC Table users, Philadelphia, Pennsylvania, April, <<http://www.epa.gov/reg3hwmd/risk/human/index.htm>>.

U.S. Environmental Protection Agency (EPA), 2004b, *User’s Guide and Background Technical Document for Region 9 Preliminary Remediation Goals (PRG) Table*, Region 9,

San Francisco, California, October,
<<http://www.epa.gov/region09/waste/sfund/prg/files/04usersguide.pdg>>.

U.S. Environmental Protection Agency (EPA), 1995, *Supplemental Guidance to RAGS: Region 4 Bulletins Human Health Risk Assessment*, Waste Management Division, Atlanta, Georgia, November.

U.S. Environmental Protection Agency (EPA), 1991, *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals), Interim*, Office of Emergency and Remedial Response, Washington, D.C., December (EPA/540/R-92/003).