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October 5, 2005

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**Submittal of the Final Baseline Human Health Risk Assessment of Groundwater
Work Plan, Revision 1
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, and those received on the January 31, 2005 version, are attached to this Final and have been incorporated into the text. Also, the May 23, 2005 technical memorandum, "Use of Analytical Data in the Groundwater Baseline Human Health Risk Assessment," has been appended (Appendix A) along with responses to Ohio Environmental Protection Agency comments on this memorandum.

Should you have any questions or require additional information regarding this submittal, please do not hesitate to call me at (865) 694-7496 or Tom Siard at (865) 694-7377.

Sincerely,

Steven T. Downey, P.E.
Project Manager

Enclosures

Mrs. Linda Ingram
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October 5, 2005

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

Prepared For:

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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	centimeters per hour
COC	chemical of concern
COPC	chemical of potential concern
CSEM	conceptual site exposure model
D&M	Dames & Moore, Inc.
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 index
HQ	hazard quotient
ILCR	incremental lifetime cancer risk
IRIS	Integrated Risk Information System
IT	IT Corporation
kg	kilogram
K _p	permeability coefficient

List of Acronyms (Continued)

L/day	liters per day
m ³	cubic meter
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

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 on standby or inactive status. On April 18, 1978, NASA declared approximately 2,152 acres of PBOW as excess. The Perkins Township Board of Education acquired 46 acres of the excess land and uses this area as a bus transportation area. GSA obtained ownership of the remaining excess acreage and currently has a use agreement with the Ohio National Guard for 604 acres of this land. NASA presently controls approximately 6,400 acres and is using the site to conduct space research as a satellite operation facility of the John Glenn Research Center.

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 PBOW. The perched water within the five AOCs included in this work plan (TNTA, TNTB, TNTC, PRRWP Area, and WARWP Area) is isolated, discontinuous, and seasonally dependent, generally resulting in low and undependable production where it exists. Therefore, perched groundwater is not a suitable drinking water source in these AOCs. 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 the following potential future uses of all or portions of the facility:

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

1.4 Protocol for the Baseline Human Health Risk Assessment

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 I, 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, D.C., 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, 1997a, *Exposure Factors Handbook*, Office of Research and Development, National Center for Environmental Assessment, Washington, D.C., 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 Baseline Human Health Risk Assessment

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 wells, overburden wells, and overburden direct-push groundwater samples 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], 2005), 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.

Because of possible turbidity issues, particularly with respect to the bailer-collected samples, a May 23, 2005 Technical Memorandum was prepared by Shaw to evaluate which samples for each well should be included in the BHHRA. The Technical Memorandum and accompanying

data tables were reviewed by OEPA, and the USACE/Shaw responses to OEPA comments on this Technical Memorandum were accepted by OEPA during the PBOW team meeting on September 15, 2005. The Technical Memorandum and responses to comments are attached to this Work Plan as Appendix A. For the BHHRA, the following protocol was used to select monitoring well samples for evaluation of groundwater at each AOC as well as the property boundary:

- All unfiltered monitoring well analytical data resulting from low-flow samples were evaluated for inclusion unless rejected because of a data quality issue (see Section 2.1.2).
- Natural site conditions are present that may introduce turbidity, such that even samples collected by low-flow methodology may be noticeably turbid. This may be especially true for wells that have naturally occurring hydrogen sulfide (refer to the Technical Memorandum in Appendix A). A review of the unfiltered low-flow data revealed that all low-flow samples had turbidities of 150 nephelometric turbidity units or less.
- For each unfiltered bailer-collected sample having a turbidity reading above 150 nephelometric turbidity units, a sample-by-sample comparison was performed to determine whether these high-turbidity samples yielded inorganics results that were consistent with those of other samples collected from that well.
- Where it was determined that high turbidities did not have an appreciable impact on inorganics concentrations, these high-turbidity unfiltered samples were included as part of the data set evaluated in the BHHRA. For high-turbidity unfiltered samples having inorganics concentrations that were accordingly higher than those of other samples from that well, the inorganics data for that sample were excluded from the BHHRA.
- For all analytes other than inorganics, the results of samples collected by bailer and low-flow technique were used unless rejected because of data quality issues (Section 2.1.2).

The turbidity evaluation summarized above resulted in the exclusion of inorganics results from five unfiltered bailer-collected samples for the BHHRA. These include the 1997 sample from BED-MW14, the 1998 sample collected from TNTC-MW3, the 1998 sample collected from IT-MW10, the 2001 sample from TNTA-MW11, and the July 2002 sample from BED-MW24. The Technical Memorandum considered the use of filtered samples to replace the unfiltered aliquots which showed unusually high turbidity, but OEPA commented that the results of filtered samples should not be combined with those of unfiltered samples under any circumstances. Consistent

with this OEPA position, no filtered data will be used in the risk assessment (See Response to OEPA Comment No. 1a on the Technical Memorandum).

In addition to the monitoring well samples, overburden groundwater samples were collected using direct-push technology from TNTA, TNTB, TNTC, and the two former red water pond areas. TNTA and TNTC direct-push samples were collected in September/October 2000 as part of the remedial investigation (IT, 2001b), the PRRWP and WARWP direct-push samples were collected in June 1998 (IT, 2000b), and two samples each were collected from the three former TNT areas in 2001 (Shaw, 2003). Additional direct-push sampling locations were planned for the 2001 sampling effort, but further collection was abandoned due to a paucity of groundwater in the overburden. 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 due to turbidity issues and will not be used in the BHHRA. Based on review of filtered and unfiltered nitroaromatics sampling results at other sites, it has been observed that turbidity does not generally have a notable effect on nitroaromatics concentrations. Therefore, all validated analytical organics data from these direct-push samples will be used in the BHHRA, unless rejected because of data quality issues (Section 2.1.2). However, it is noted that differences in sampling technique between collection from monitoring wells and the direct-push technique may result in differences in analytical results, and the effect of turbidity on the results of nitroaromatics and other organics cannot be entirely ruled out.

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. The following are some of the more common qualifiers and their meanings (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 $1E-6$ 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, 1995). 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 $1E-6$; acceptable exposure levels are generally concentration levels that represent an excess upper bound lifetime cancer risk to an individual of $1E-6$ to $1E-4$ (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 $1E-6$ or an HQ of 0.1, whichever associated water concentration is lower.

Certain elements are essential human nutrients that are generally regarded as innocuous at 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. Benzene, ethylbenzene, toluene, and xylenes (BTEX) 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 a 2-step approach: 1) background screening and 2) statistical data set testing. This second step (Section 2.2.3.2) will only be used in cases where the concentration used for background screening is exceeded (refer to Section 2.2.3.1) and will be addressed after the risk characterization (Section 5.0) in the uncertainty analysis (Section 6.0) of the BHHRA. 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 that 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, 2005). 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, 2005).

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 the 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 (identified in Appendix M of the 2004 groundwater data summary and evaluation report [Shaw, 2005]) may be performed for chemicals whose MDCs exceed the respective BSCs and are 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 (WRS) statistical test (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. As mentioned in Section 2.2.3, statistical testing will be performed after the risk characterization (Section 5.0) as part of the uncertainty analysis (Section 6.0). WRS will not necessarily be run on all inorganic 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. 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 Sections 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 exist 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 Chapter 5.0). As mentioned in Chapter 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 [$^{\circ}$ F], respectively), and January is generally the coldest (average high and low temperatures of 32 and 19 $^{\circ}$ F, respectively) (The Weather Channel, 2004). On average, the first freezing day (low of 32 $^{\circ}$ 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, 2005). 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, 2005). 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, 2005).

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 (IT, 2001a, 2001b, 1999b, 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 the former TNT manufacturing areas and red water ponds 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 a 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 1.3, 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 (Chapter 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 (cm²) (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. For data sets with less than five samples, the MDC is used as the EPC. Also,

because most of the downgradient boundary wells are spatially unrelated, the MDC of the combined set of boundary wells will be used as the EPC in the BHHRA.

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)
- = 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):

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

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 and 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 and 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 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 $0.25 m^3/\text{hour}$ (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 whole-house 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 after volatilization (C_d), as applicable, 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 COPCs in Groundwater

The ingested dose of COPCs 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 COPCs 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 COPCs 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) (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 cubic centimeter).

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/cm²-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 (µg/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 liters per cubic centimeter)
- J = 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 J 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 J are not available, they will be calculated using Equation 3.12 (EPA, 1992a). Values of K_p and J 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:

- J = 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/m^3)
- IR_a = inhalation rate (m^3/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 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 m³ 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 m³ of air per day and to weigh 70 kg) the mathematical conversion consists of multiplying the unit risk (per mg/m³) by 70 kg and by 1,000 micrograms per milligram, and dividing the result by 20 m³ 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 HQs 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 EPA Office of Solid Waste and Emergency Response 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 EPA Office of Solid Waste and Emergency Response 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 EPA'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 gavage 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 COPCs.

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):

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

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 ILCRs summed across pathways is the total ILCR as shown in the equation below.

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

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):

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

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 cannot 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 ith toxicant
RfD_i = reference dose for the ith 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 Areas of Concern 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 COPCs, 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 presents an overview of general sources of uncertainty and focuses 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

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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**

(Page 1 of 2)

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-GW08 ^a TNTA-GW10 ^a TNTA-DP14 ^a TNTA-DP21 ^a	PB-BED-MW18 TNTA-BEDGW-001
TNT Area B	MK-MW17 TNTB-DP02 ^a TNTB-DP03 ^a	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-GW10 ^a TNTC-DP13 ^a TNTC-DP19 ^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

Table 2-1

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

(Page 2 of 2)

Site Area	Overburden Sampling Location	Bedrock Sampling Location
Downgradient Boundary Wells	NA ^b	BED-MW17 BED-MW19 BED-MW22 BED-MW24 BED-MW27 BED-MW30

^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 _{I_{gw}}), 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 _{I_{gw}}), unitless	1 ^e	1 ^e
Body surface area exposed to water (S _{a_{gw}}), 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.

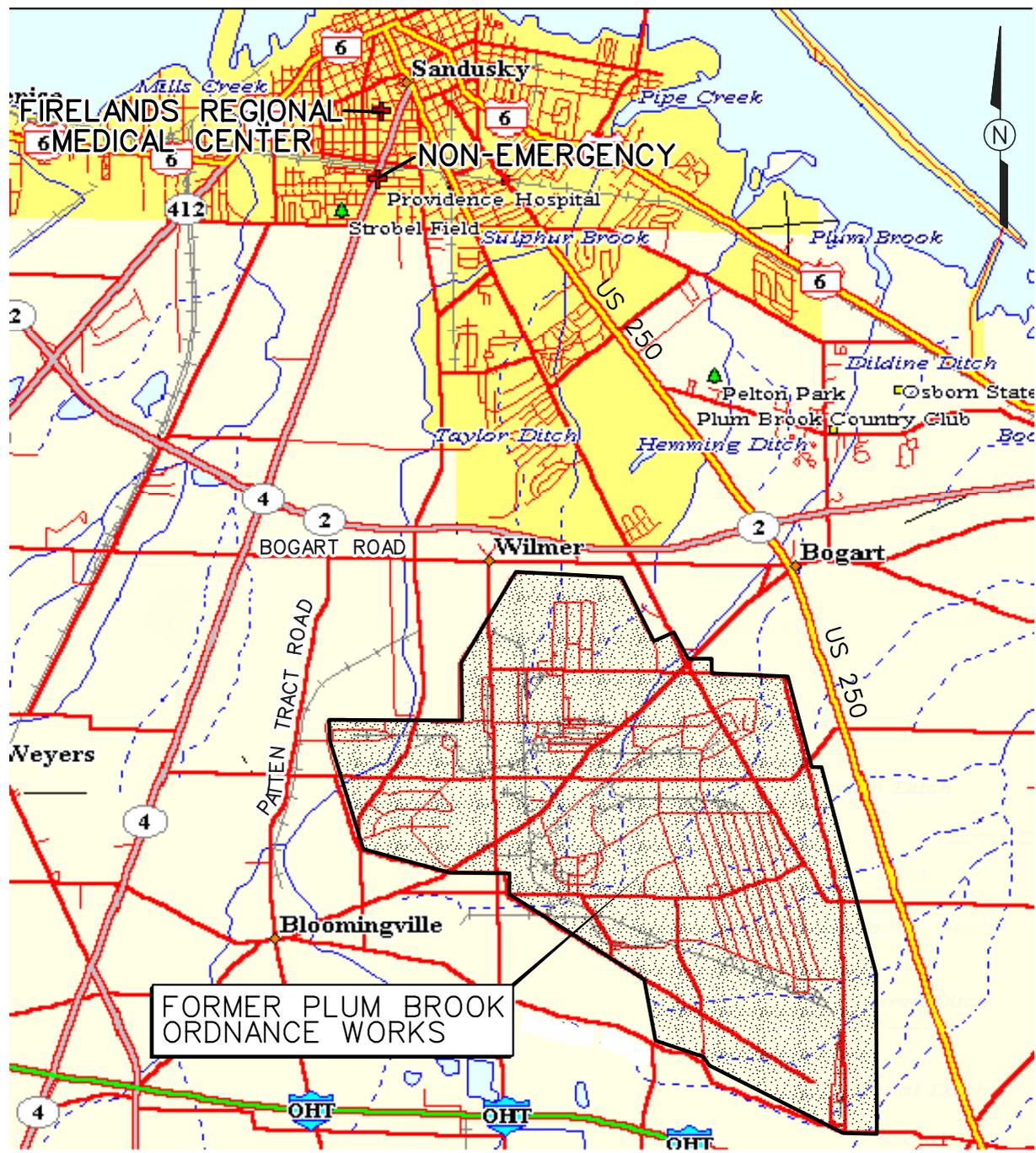
^fU.S. Environmental Protection Agency (EPA), 2004, *Risk Assessment Guidance for Superfund Volume 1: Human Health Evaluation Manual (Part E - Supplemental Guidance for Dermal Risk Assessment)*, Final, Office of Superfund Remediation and Technology Innovation, Washington, D.C., July, EPA/540/R-99/005.

^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

DWG. NO.: 833886ES.004
 INITIATOR: T. SIARD
 DRAFT, CHCK. BY:
 ENGR. CHCK. BY: T. SIARD
 DATE LAST REV.:
 DRAWN BY:
 STARTING DATE: 11/23/04
 DRAWN BY: D. BOWMAR

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 3:36:38 PM
 11/23/2004
 PBOW_standard.tbl
 dbomar
 833886es.004



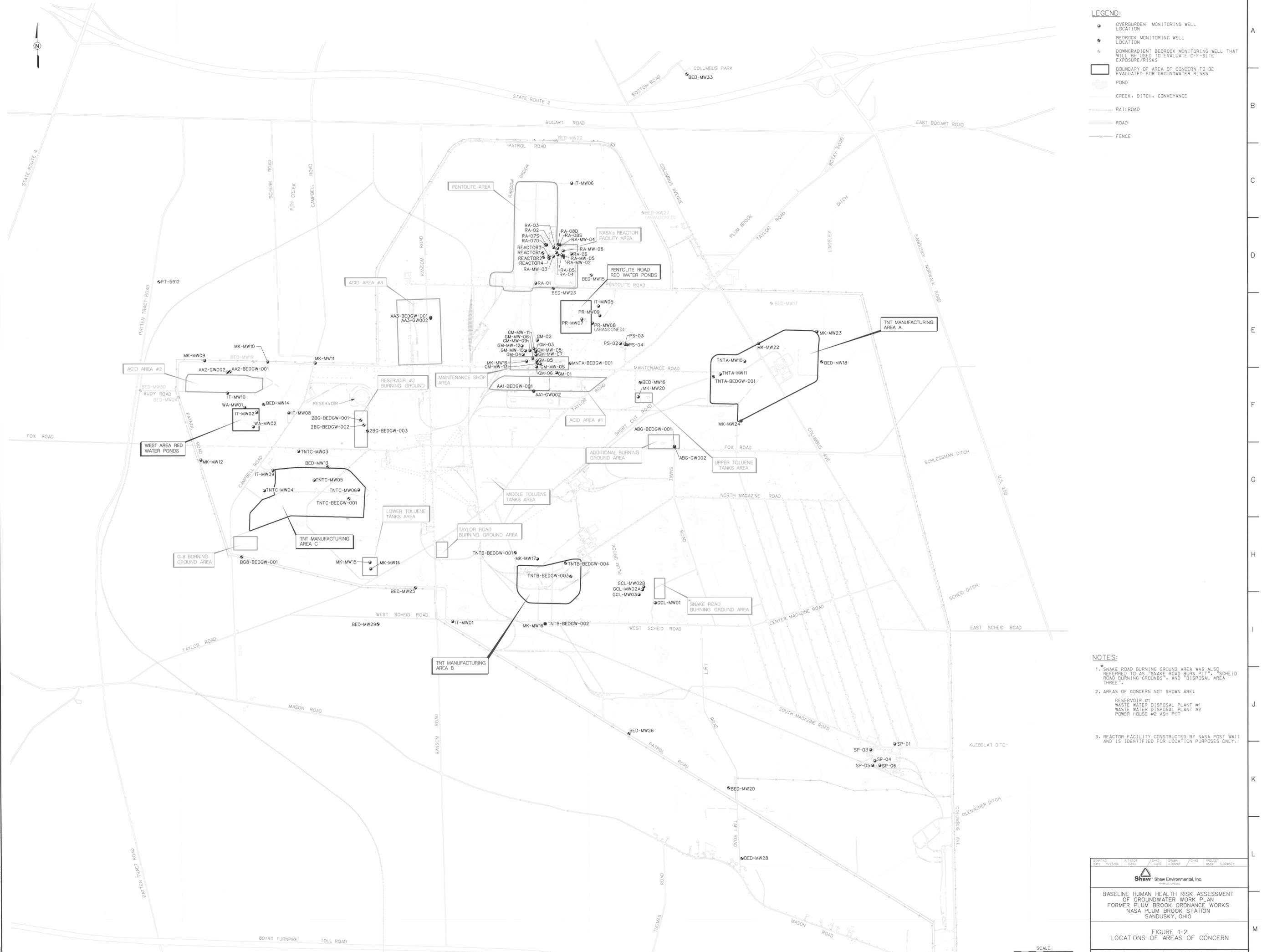
NOT TO SCALE

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



- 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



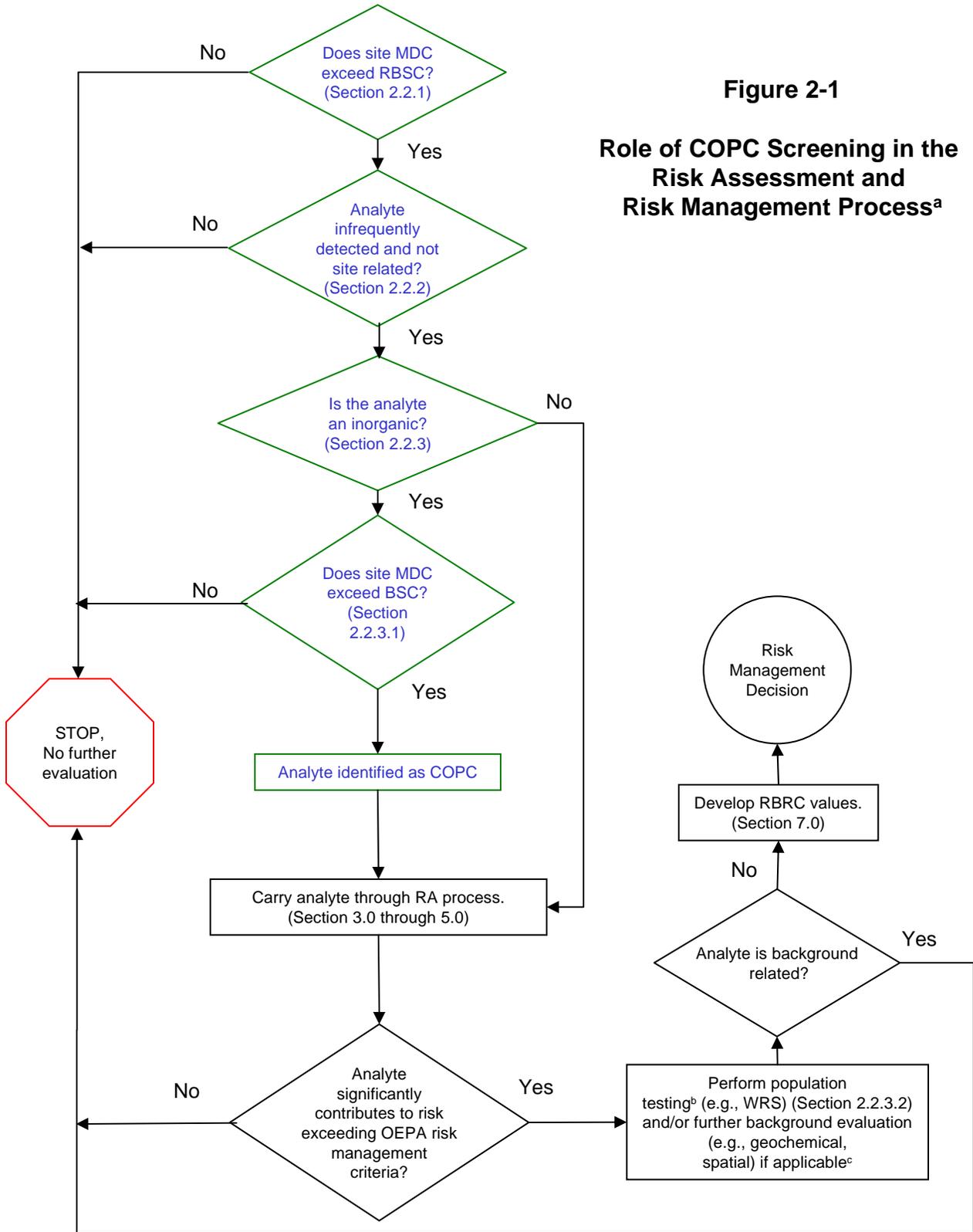
- NOTES:**
1. *SNAKE ROAD BURNING GROUND AREA WAS ALSO REFERRED TO AS "SNAKE ROAD BURN PIT", "SCHEID ROAD BURNING GROUNDS", AND "DISPOSAL AREA THREE".
 2. AREAS OF CONCERN NOT SHOWN ARE:
RESERVOIR #1
WASTE WATER DISPOSAL PLANT #1
WASTE WATER DISPOSAL PLANT #2
POWER HOUSE #2 ASH PIT
 3. REACTOR FACILITY CONSTRUCTED BY NASA POST WW11 AND IS IDENTIFIED FOR LOCATION PURPOSES ONLY.

STARTING DATE: 1/23/04	PLANNED BY: J. BARD	CHECKED BY: J. BARD	DRAWN BY: J. BARD	PROJECT NO.: 833886	SUBJECT: SANDUSKY, OHIO
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: SITEWIDE	JOB NO.: 833886	DRAWING NO.: 833886S.005	REV:		



Figure 2-1

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



Notes:

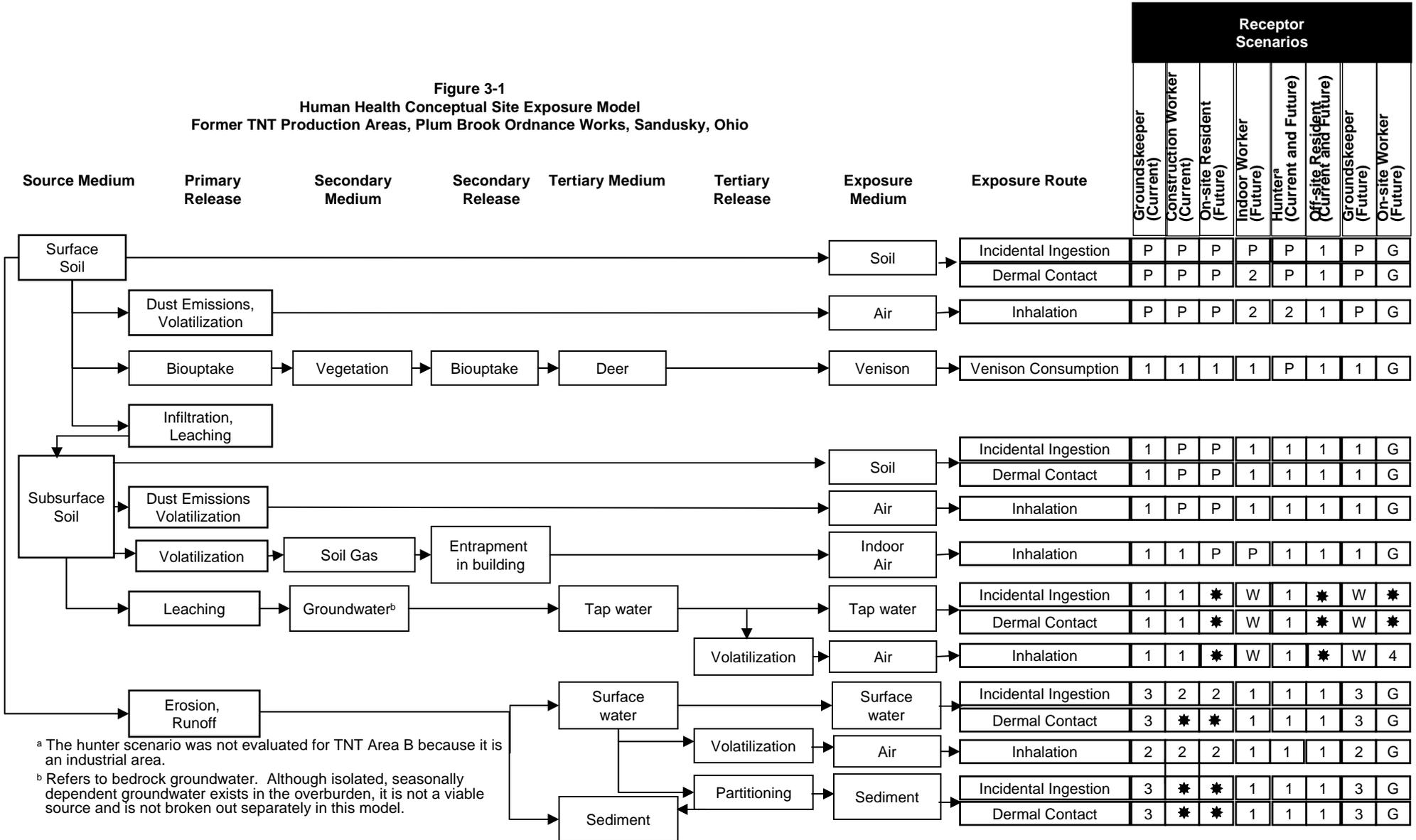
^a COPC screening steps are shown in blue.

^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.

^c Refer to Appendix M of the 2004 Groundwater Data Summary and Evaluation Report (Shaw, 2005).

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).

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 (BHHRA).

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 BHHRA's.

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.

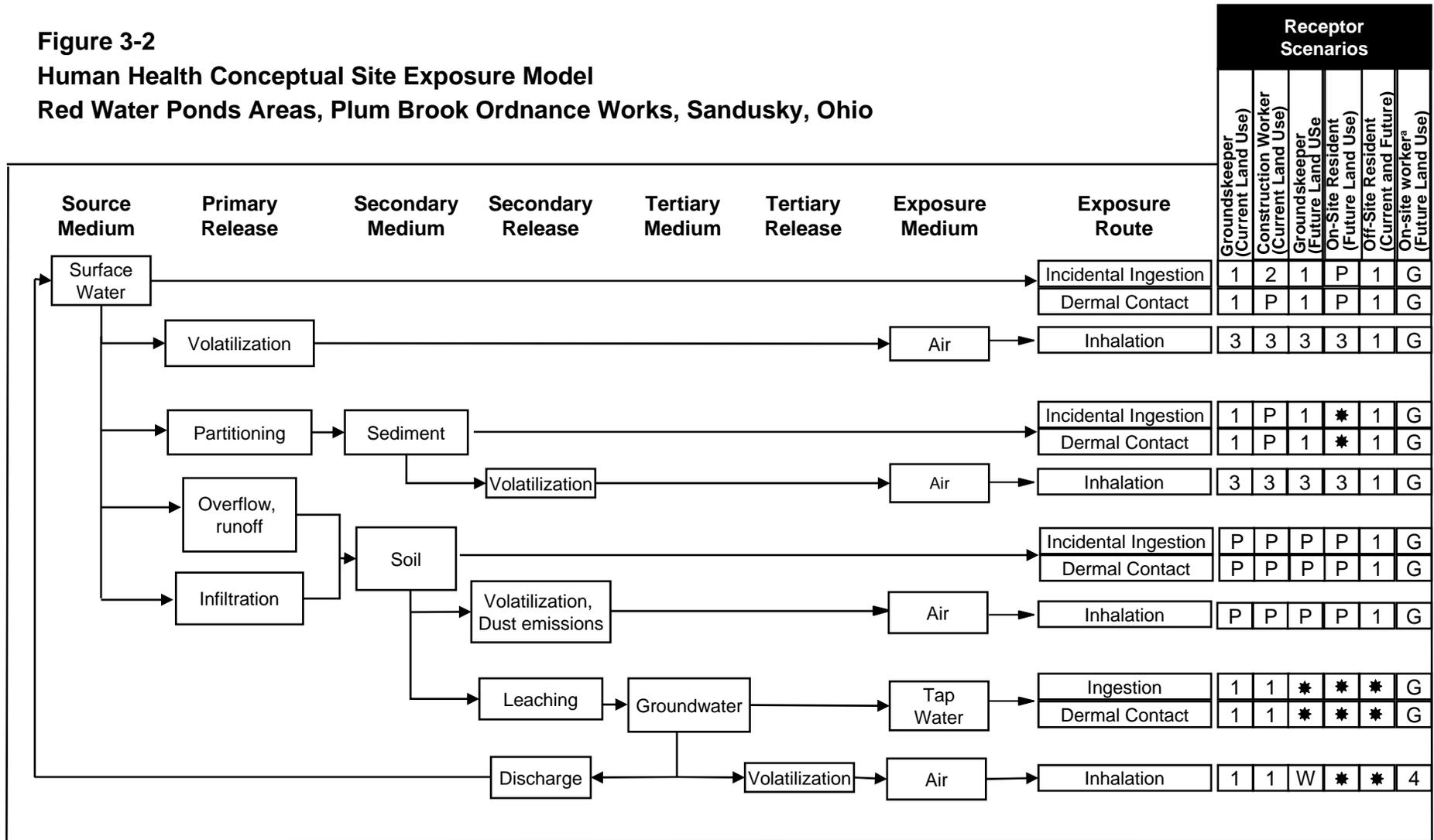
4 = Although theoretically complete, large dilution factor of ambient air obviates the need to quantify this pathway for an outdoor worker. Exposure to future indoor worker using site groundwater would not be quantifiable but would likely be insignificant compared to other pathways.

P = Complete exposure pathway evaluated in the previous BHHRA's 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 BHHRA's 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 BHHRA.
 W = Groundwater exposure/risks evaluated as future on-site worker (see note for "G").

APPENDIX A

**TECHNICAL MEMORANDUM AND ASSOCIATED
RESPONSE TO COMMENTS**

Technical Memorandum

TO: L. Ingram, Project Manager, U.S. Army Corps of Engineers, Nashville District

FROM: M. Gunderson (Technical Leader) and T. Siard (Risk Assessor), Shaw Environmental, Inc.

DATE: May 23, 2005

SUBJECT: Use of Groundwater Analytical Data in the Groundwater Baseline Human Health Risk Assessment, Plum Brook Ordnance Works, Sandusky, Ohio

This technical memorandum was prepared in response to Comment No. 1 in the March 3, 2005 Ohio Environmental Protection Agency (OEPA) comment letter on the draft Baseline Human Health Risk Assessment for Groundwater (BHHRA) Work Plan (Shaw, 2005) concerning the use of samples other than unfiltered samples collected using low flow methodology (OEPA, 2005). Consistent with the 2004 Groundwater Data Summary and Evaluation Report (Shaw, 2004), the BHHRA will include analytical data from 1997 through the most recent samples collected. During this period, groundwater sampling has been conducted at the former Plum Brook Ordnance Works (PBOW) using two sampling methods: bailer and low flow. It is our intent to make best use of the data sets so that the most representative data are used in the evaluation of groundwater associated with PBOW. The analytical data files accompany the electronic transmission of this memo.

Prior to September 2001, monitoring wells were purged of three to five well volumes of groundwater using either submersible pumps or bailers, and groundwater samples were collected with a bailer. It has long been recognized that this approach may not produce representative groundwater analytical data due to higher turbidity generated by the surging action of bailer insertion and removal. In particular, inorganics data can be significantly elevated in samples collected with a bailer. Beginning in September 2001, groundwater sampling was conducted using the low flow (minimal drawdown) method unless groundwater recharge was insufficient. Low flow sampling minimizes disturbance in the well and is thought to produce more representative data and minimize the need for sample filtration. Note that a number of the wells, especially the overburden wells, were collected only by bailer either due to insufficient recharge or because all samples from these wells were collected prior to September 2001.

The objectives of this technical memorandum are to provide a review of existing site data, evaluate the appropriateness of using bailer-collected data in the BHHRA, and provide recommendations as to which samples should be used to characterize each well. This memorandum makes a recommendation for each sample from each well as to whether filtered or unfiltered bailer-collected data are more appropriate for inclusion in the final data set. Even though the perched overburden groundwater will not be

quantitatively evaluated in the BHHRA, analytical results from overburden wells are also included in this evaluation so that the most appropriate concentrations are used for the qualitative evaluation and groundwater modeling efforts. Further, the memorandum also presents an evaluation of all the data, including low flow, to determine whether any of the samples appear to be inconsistent with the rest of the data from that well and should, thus, be eliminated from the data set.

1.0 Data Evaluation Process

Under the groundwater investigation programs at PBOW, a total of 18 overburden and 15 bedrock wells identified in the draft BHHRA work plan were sampled from 1997 through 2004. Each of these wells was sampled at least twice, and some were sampled as many as 10 times during this period. Unfiltered samples were collected from these wells using either low flow or bailer. Where sufficient water quantity was available, which was typically the case, an aliquot was also collected from each well for filtered inorganics analysis. Sample filtration was conducted in the field using a 0.45-micron filter. In-line filters were used for samples collected by low flow sampling. For bailer collected samples, a hand operated vacuum pump was used.

Low flow has been used since September 2001, except under conditions of insufficient recharge. The discrepancies between filtered and unfiltered data in PBOW wells sampled using low flow methodologies indicate that low flow sampling cannot reduce turbidity under certain hydrogeologic conditions. Specifically, wells installed in the Delaware Limestone have naturally occurring hydrogen sulfide. A review of the data indicates that wells with elevated hydrogen sulfide do not show consistent patterns of turbidity. These variations are thought to be the result of changing water levels during the sampling periods which influence the amount of hydrogen sulfide released by the formation. Release of gaseous hydrogen sulfide into the monitoring well causes turbulent flow and may elevate the concentrations of inorganics.

Interpretation of the turbidity data does not provide a consistent “bright line” above which one can attribute to sampling artifacts. However, it was observed during a review of all the groundwater data from the wells identified in the BHHRA work plan that low flow sampling generally produces data with turbidities of less than 150 NTUs. Based on the recommendation that all unfiltered low flow data will be used in the risk evaluation, the turbidity value of 150 NTUs is used as the criteria above which further evaluation of the sampling data was conducted in this technical memorandum.

In addition to turbidity, the reproducibility of groundwater data is evaluated using the Relative Percent Difference (RPD) between two samples. Typically, this is used to evaluate the reproducibility of analytical results for primary and duplicate samples. For the PBOW site, a RPD of less than 30% is considered acceptable for sample duplicates. Similarly, an RPD of less than 30% for a filtered and unfiltered sample pair would suggest that the results are within the acceptable range of analytical variation. The RPD in this evaluation is used to aid the evaluation of the affects of turbidity on inorganics

concentrations. If the criterion of 30% is exceeded for any given filtered/unfiltered sample pair, it can be assumed that this is due to turbidity. There are no set guidelines however, that would indicate if the observed turbidity and/or the difference in RPDs is artificially induced by sampling methodology or if it is characteristic of the aquifer. But, if numerous sampling rounds are conducted on a given well, the evaluation of the turbidity and the RPD values can be used to assess the potential impacts of the sampling methods used.

The RPD is calculated as follows:

$$\text{RPD} = 100 \times (S1-S2)/[(S1 + S2)/2]$$

Where: S1 = primary (unfiltered) sample concentration
S2 = duplicate (filtered) sample concentration

By the convention stated above for the RPD calculation, a negative RPD indicates that the filtered sample concentration is higher than the unfiltered sample concentration. Two factors can affect the relevance of the RPD calculation. First, data having contamination in the associated sample blank is not relevant. Second, for analytes detected at very low concentrations (e.g., less than 5 ppb), the samples RPD may be greater than 30% but this is a less significant variation than a similar RPD at much higher concentrations. This is because variations of low magnitude (attributable to analytical or other sources) can more significantly affect the RPD at low concentrations.

2.0 Well-by-Well Evaluation

A well-by-well evaluation of the analytical results was conducted based on turbidities, comparison of unfiltered versus filtered data for each sampling event, and comparison across sampling events. The following evaluation presents the analytical evaluation of wells that had at least one sample with a turbidity measurement of greater than 150 NTUs. The evaluations are organized by area to be evaluated in the BHHRA. The results and recommendations of this evaluation, as well as the potential bias associated with accepting these recommendations are presented below and are summarized on Table 1. Note that for completeness, Table 1 also includes wells in which no sample had a turbidity reading exceeding 150 NTU; these wells are not evaluated in the text below.

2.1 TNTA Wells

TNTA-MW11. Overburden well TNTA-MW11 was sampled four times (1997, 1998, 2001 and 2002). Because of insufficient recharge, each of these samples was collected by bailer. Turbidity was elevated (536 NTUs) in the sample collected in 1998 but was much lower (77 and 56.4 NTUs) in 1997 and 2002. Because of limited water in the well during the 2001 sampling event, the filtered sample and the water quality parameters could not be collected. With the exception of the 2001 data, the concentrations of

analytes detected were relatively consistent in all of the samples. In the 2001 data, cadmium, cobalt, and copper were detected in addition to the analytes detected in the other sampling events. In situations where insufficient water is available to collect all samples, the sample is typically very turbid. It is likely that the detection of cadmium, cobalt and copper as well as elevated concentrations of other parameters are likely due to suspended sediment. Therefore, the sample collected in 2001 should be removed from the data set.

Based on these findings, all of the unfiltered data appears to be representative of the overburden groundwater in this location except for the 2001 results. Because of the limited water in this well during 2001 and the correspondingly high turbidity, it is recommended that this sample be removed from the data set. Based on review of the analytical results, use of only the three remaining unfiltered samples introduces no apparent bias.

MK-MW22. Turbidity was measured at 132 and 988 NTUs in the bailer samples collected from this overburden well in 1997 and 1998, respectively. Unlike most of the other overburden wells that have this great a variation in measured turbidities, the inorganics detected and the actual concentrations in both filtered and unfiltered samples in these two sampling events are nearly identical. The reason for this is unclear, but it suggests that most of the inorganics are in dissolved form and are likely to be representative of overburden groundwater at this location. Based on the similarity of the data, the results from both unfiltered samples are recommended for inclusion in the final data set. Based on review of the analytical results, use of the two unfiltered samples introduces no apparent bias.

MK-MW23. This overburden well was sampled by bailer in 1997 and 1998. The turbidity measured in 1997 was 602 NTUs compared to 154 NTUs in 1998. Both samples show RPDs exceeding 30% for numerous analytes. With the exception of sodium, the concentrations of inorganics in the unfiltered sample from 1998 were higher than those detected in 1997. In the filtered samples from both events, only arsenic, calcium, magnesium, manganese, and potassium were detected. The detections in the filtered samples are more consistent with other PBOW wells.

Based on the elevated turbidity in both wells and the large discrepancies in the unfiltered and filtered samples, entrained sediment has affected both samples. However, between the two unfiltered samples, the sample with the lower turbidity (1998) had higher concentrations than the sample with the higher turbidity (1997). Even though the turbidities in these unfiltered samples are relatively high, it is recommended that the results of these unfiltered samples be included in the BHHRA because: 1) Low-flow methodology has not been used to collect samples from this well to provide a basis for comparison, 2) Based on the limited number of samples collected from this well, it cannot be definitively stated that the levels of turbidity encountered in 1997 and 1998 are uncharacteristic of this well, 3) Correlation of concentrations between the two unfiltered samples indicate an inexplicable negative relationship with turbidity, and 4) No other information suggests that analytical results from this well are questionable. Inclusion of

the unfiltered samples, especially the 1998 sample, may introduce a high bias to the analytical data evaluation for numerous inorganics.

2.2 TNTB Wells

TNTB-BED-GW003. Bedrock well TNTB-BED-GW003 was sampled in 2001 and 2002 by bailer because of insufficient recharge. Turbidities were 370 and 9250 NTUs, respectively. Aluminum, arsenic, barium, calcium, chromium, cobalt copper, iron, lead, magnesium, manganese, mercury, nickel, potassium, selenium, sodium, vanadium and zinc were detected in the unfiltered 2001 sample; each of these except mercury was also detected in the 2002 sample. The filtered samples had fewer detections and, for most analytes, had much lower concentrations. This indicates that inorganics concentrations observed in the unfiltered samples are associated with suspended sediments resulting from bailing this low-producing well with a limited water column. Based on the following, it is recommended that the unfiltered samples be used in the final data set: 1) Low-flow methodology could not be used to collect samples from this well to provide a basis for comparison, 2) Based on the limited number of samples collected from this well and limited water column, it is likely that high turbidity is characteristic of this well. 3) No other information suggests that analytical results from this well are questionable. Inclusion of the unfiltered samples from this well in the final data set introduces a high bias.

2.3 TNTC Wells

TNTC-MW3. This well was sampled in 1997, 1998 and 2002. The turbidity in the 1998 sample was measured at >999 NTUs, with the 1997 and 2002 samples having turbidity values of 9 and 59 NTUs, respectively. Because of insufficient recharge, each of these samples was collected by bailer. The results from the 1997 and 2002 sampling events are consistent in terms of the analytes detected. In addition to the high turbidity reported in the 1998 sample, elevated concentrations of aluminum and iron as well detections of arsenic, chromium, copper and lead not seen in the other sampling events suggest that these are the result of suspended sediment. The filtered 1998 sample was more consistent with the unfiltered 1997 and 2002 data, but generally had lower concentrations.

It is recommended that the unfiltered 1998 sample be excluded from the data set for the following reasons: 1) Excessively high turbidity was not encountered during the other sampling events, 2) Concentrations of analytes were high in comparison to the other sampling events, and 3) Detection of analytes that were not encountered in the other sampling events. It is recommended that the filtered 1998 sample not be included because the associated concentrations are generally less than those detected in the unfiltered 1997 and 2002 samples.

The 1997 and 2002 unfiltered samples are interpreted to be representative of the overburden groundwater in this area and are recommended for inclusion in the final data set; thus, no particular high or low bias is interpreted as associated with the use of these two samples to represent groundwater in this area.

TNTC-MW4. Overburden well TNTC-MW4 was sampled four times (1997, 1998, 2001 and 2002). Because of insufficient recharge, each of these samples was collected by bailer. Elevated turbidities were observed in the 1998 (>999 NTUs) and 2002 (178 NTUs) data. In the other two samples, turbidity ranged from 19 to 22 NTUs. The analytical data however, is relatively consistent in all samples, both in the analytes detected and in their concentrations in the unfiltered samples. Because of the consistent concentrations, it is recommended that all unfiltered samples be retained in the final data set. Based on review of the analytical results, use of the four unfiltered samples introduces no apparent bias.

IT-MW09. Overburden well IT-MW09 was purged and sampled by bailer in 1997 and 1998. In the 1997 unfiltered sample, aluminum, chromium, and iron exceeded the RPD criteria. The turbidity in the sample was 256 NTUs. In the 1998 unfiltered sample, the same analytes were detected with the exception of chromium and zinc. The concentrations were lower however, presumably due to the lower turbidity (154 NTUs) in this sample. All of the analytes that were detected in the 1998 unfiltered sample were also detected in the 1997 filtered sample, albeit the filtered sample had higher concentrations detected. Additionally, the 1997 filtered samples included a detection of zinc whereas the 1998 unfiltered sample did not. These observations may be due to some seasonal variation in groundwater since the 1997 sample was collected in November, and the 1998 sample was collected in May. The data suggests that the unfiltered, highly turbid 1997 sample is not representative of the groundwater. The only analytes affected by this are aluminum, chromium and iron. The similarities in concentrations between the filtered and unfiltered data sets also indicate that most of the inorganics are in dissolved form.

It is recommended that the 1998 unfiltered sample be included in the data set. Even though the turbidity of the 1997 unfiltered samples is relatively high, it is recommended that the results of this sample be included in the BHHRA because: 1) Low-flow methodology has not been used to collect samples from this well to provide a basis for comparison, 2) Based on the limited number of samples collected from this well, it cannot be definitively stated that the turbidity encountered in 1997 is uncharacteristic of this well, 3) The concentrations associated with the unfiltered 1997 sample do not appear to be excessively high, and 4) No other information suggests that analytical results from this well are questionable. Inclusion of the 1997 unfiltered sample may introduce a high bias to the analytical data evaluation, especially with respect to aluminum, chromium, and iron.

PB-BED-MW13. Bedrock well PB-BED-MW13 was sampled four times (1997, 1998, 2001 and 2002) with turbidity ranging from 50 to 585 NTUs. All of the samples were collected with a bailer. The analytical data however, is relatively consistent in all samples, both in the analytes detected and in their concentrations in the unfiltered samples. Because of the consistent concentrations, it is recommended that all unfiltered samples be retained in the final data set. Based on review of the analytical results, use of the four unfiltered bailer samples introduces a no apparent bias.

2.4 Pentolite Road Red Water Pond Area Wells

IT-MW05. Overburden well IT-MW05 was purged and sampled by bailer in 1997 and 1998. Turbidity was high in both samples, with recorded readings of 78 and 380 NTUs, respectively. Both samples had numerous exceedances of the RPD criteria, suggesting both have been affected by the sampling method. With the exception of barium and copper in the 1998 sample, both samples had the same analytes detected, although the actual concentrations were much higher in the more turbid 1998 sample. The filtered aliquot from the 1998 sampling event had calcium, magnesium, manganese and sodium detected at similar concentrations as the 1997 unfiltered sample. However, arsenic, chromium, and lead were not detected in the filtered 1998 sample, but were reported in the unfiltered 1997 sample. Lower concentrations were detected in the unfiltered 1997 samples than in the unfiltered 1998 sample, corresponding with the lower turbidity of the former. Even though the turbidity of the 1998 unfiltered sample is relatively high, it is recommended that the results of this sample be included in the BHHRA because: 1) Low-flow methodology has not been used to collect samples from this well to provide a basis for comparison, 2) Based on the limited number of samples collected from this well, it cannot be definitively stated that the turbidity encountered in 1998 is uncharacteristic of this well, 3) The concentrations associated with the unfiltered 1998 sample do not appear to be excessively high in comparison to the 1997 sample, and 4) No other information suggests that analytical results from this well are questionable. Inclusion of the 1998 unfiltered sample may introduce a high bias to the analytical data evaluation, especially with respect to aluminum, barium, chromium, copper, and manganese.

PR-MW7. This overburden well was sampled by bailer in 1997 and 1998 and had turbidities of >999 and 3 NTUs. Data from the two sampling events are nearly identical both in terms of the analytes detected and their concentrations in both the unfiltered and filtered samples. Again, this is likely the result of most of the inorganics being in dissolved form. Because of the similarity of the data, both unfiltered samples are recommended for inclusion in the final data set. Based on review of the analytical results, use of the two unfiltered samples introduces no apparent bias.

PR-MW8. Overburden well PB-PR-MW8 was sampled by bailer in 1997 and 1998 and had turbidities of >999 and 99 NTUs. Data from the two sampling events are nearly identical both in terms of the analytes detected and their concentrations in both the unfiltered and filtered samples. As with the data from well PB-PR-MW7, most of the inorganics are in dissolved form. Because of the similarity of the data, both unfiltered samples are recommended for inclusion in the final data set. Based on review of the analytical results, use of the two unfiltered samples introduces no apparent bias.

PR-MW9. This overburden well was sampled by bailer in 1997 and 1998 and had turbidities of 170 and 9 NTUs. Data from the 1997 sampling event is anomalous, with only manganese and sodium reported in both filtered and unfiltered samples. In the 1998 unfiltered sample, cobalt, copper, iron, magnesium, manganese, nickel and sodium were detected. Concentrations observed in the 1998 filtered and unfiltered samples were

similar, except for iron which was not detected in the filtered sample. Because of the similarities of the two samples with respect to comparison between filtered and unfiltered aliquots, it is recommended that both unfiltered samples be included in the final data set. Despite this consistency, however, the 1997 data appear to be anomalously low.

2.5 West Area Red Water Ponds Wells

WA-MW2. Overburden well PB-WA-MW2 was sampled by bailer in 1997 and 1998, and each of the unfiltered samples had a turbidity of greater than 999 NTUs. In the 1998 unfiltered sample, aluminum, chromium, cobalt, copper, iron, magnesium, manganese, nickel, potassium, selenium, sodium, and zinc were detected. These same analytes, minus selenium and zinc, were detected in the 1998 unfiltered sample. Detected concentrations were very similar for the 1997 and 1998 unfiltered samples. The list of detected compounds and concentrations were likewise very similar for the 1998 filtered and unfiltered samples. However, only calcium, manganese, magnesium, and sodium were detected in the 1997 filtered sample.

It is recommended that both unfiltered samples be used in the final data set for the following reasons: 1) Despite very high turbidity measurements, little or no effect of filtration was observed in the 1998 samples, and 2) Concentrations of the 1997 and 1998 unfiltered samples were consistent. It is possible that inclusion of these samples with high turbidity may introduce a high bias; however, based on the similarity between the unfiltered and filtered 1998 samples, these samples are likely characteristic of site conditions.

IT-MW10. This overburden well was sampled by bailer in 1997 and 1998 with turbidities of the unfiltered samples at 1 and >999 NTUs, respectively. This great variation in turbidity readings indicates that sampling methodology probably affected the data quality in the latter sample. In 1997, aluminum, calcium, iron, lead, magnesium, manganese, and sodium were detected in the unfiltered samples. In 1998, the same analytes were detected as well as arsenic, barium, chromium, copper, potassium, vanadium and zinc. The concentration of iron and lead were much higher in the 1997 unfiltered sample than in the 1998 unfiltered sample. Aluminum, iron and lead exceeded 30% RPD in the 1997 samples. In 1998, aluminum, barium, chromium, copper, iron, lead, potassium, vanadium and zinc exceeded the RPD of 30%. The higher number of analytes exceeding the RPD in the 1998 sample was probably due to entrained sediment.

Based on this review, it is recommended that the unfiltered 1997 data and the filtered sample from the 1998 sampling event be used in the data set. Exclusion of the 1998 unfiltered sample is recommended for the following reasons: 1) Excessively high turbidity (>999 NTU) as compared to the low turbidity of the 1997 unfiltered sample (1 NTU), 2) Among the two filtered and two unfiltered samples, five analytes were detected only in the unfiltered 1998 sample and two were detected at much higher concentrations in this sample than in any of the other three. Because only two samples were collected from this well, it is better to include the 1998 filtered sample than to use only the 1997 unfiltered sample. Use of the filtered 1998 sample may introduce a low bias to the

analytical data evaluation; however, the magnitude of the bias with respect to the samples from this well likely do not correspond with the magnitude of difference between the unfiltered 1998 sample and the other three sample aliquots collected from this well.

BED-MW14. Bedrock well PB-BED-MW14 was sampled four times (1997, 1998, 2001 and 2002). The samples collected in 1997 and 1998 were collected by bailer, and the remaining two were collected by low flow. The turbidities of the samples were 269, 36, 5, and 9 NTUs, respectively. Review of the analytical data indicates that most of the analytes were detected at their highest concentrations in the sample collected in 2002 (9 NTU) using low flow methodology. Results of the unfiltered and filtered results for the 2002 samples indicate a high degree of consistency. This consistency is also observed in the 1998 and 2001 filtered versus unfiltered results.

Aluminum, chromium, and iron were detected at their highest concentrations in the PB-BED-MW14 sample collected in 1997. None of these analytes were detected in the corresponding 1997 filtered sample. However, each of the other analytes detected in the unfiltered 1997 sample was also detected in the filtered sample at a similar concentration. Therefore, concentrations of aluminum, chromium, and iron in this sample are evidently associated with turbidity.

It is recommended that the unfiltered sample results for the 1998, 2001, and 2002 be retained in the final data set, along with the filtered results for the 1997 sample based on the following: 1) Turbidity measurement for the 1998, 2001, and 2002 samples are less than 150 NTU and show consistency between filtered and unfiltered samples, 2) The unfiltered sample result from 1997 showed high turbidity, 3) High concentrations of three analytes (aluminum, chromium, and iron) in the 1997 unfiltered samples were associated with turbidity, and 4) Other analytes detected in the 1997 samples showed no effects from filtration, and 5) Inclusion of the filtered sample from 1997 helps to better characterize this data set. Based on review of the analytical results, inclusion of the filtered data from 1997 introduces a potential low bias.

2.6 Downgradient Boundary Wells

BED-MW17. Bedrock well BED-MW17 was sampled in 1997 and 1998 by bailer and in 2001, 2002, and 2004 (twice) using low flow. Turbidities ranged from 11 NTUs to 412 NTUs at the time of sampling. While the three lowest turbidity readings (11, 21 and 134 NTUs) were obtained using low flow sampling, the highest turbidity reading of 412 NTUs was also seen during low flow sampling. The remaining two sampling events were completed using bailers and the turbidity readings were 213 and 318 NTUs. The high turbidity observed in the low flow sample as well as the two bailer samples was due to the release of hydrogen sulfide in the aquifer, which tends to create turbulent flow in the well and hence, more suspended sediment. Regardless, review of the analytical results for this well does not indicate a great variation in either the analytes detected or their concentrations between sampling events. This similarity suggests that most inorganics are present in dissolved form, as does a comparison between filtered and unfiltered aliquots collected during each sampling event. The interpretation of inorganics

present chiefly in dissolved form is consistent with the reducing conditions present in this well as evident by the hydrogen sulfide. Based on these observations, it is recommended that all six unfiltered samples be used in the final data set. Use of these six unfiltered samples, including two low flow samples, introduces no apparent bias.

BED-MW24. Bedrock well PB-BED-MW24 was sampled a total of ten times in 2001, 2002 and 2004. Nine of these were collected using low flow sampling. Review of the analytical data indicates the data from the sample collected in July 2002 is anomalous. This was the only unfiltered sample with an elevated turbidity reading (350 NTUs). The concentration of numerous analytes including aluminum and iron are much higher than the other samples. In addition, chromium and vanadium were detected in this sample but not the remaining samples. Review of the sample collection logs indicate that this well can produce hydrogen sulfide which likely resulted in the elevated turbidity reading and higher concentrations in this single sampling period. It is recommended that this single sample collected in 2002 be removed from the data set. The remaining nine unfiltered samples provide adequate characterization for this well, and their use introduces no apparent bias.

3.0 References

Ohio Environmental Protection Agency (OEPA), 2005, Comment letter from Ron Nabors (OEPA Site Coordinator) to Linda Ingram (USACE Project Manager) regarding the Plum Brook Baseline Human Health Risk Assessment of Groundwater Work Plan, March 3.

Shaw Environmental, Inc. (Shaw), 2005, **Baseline Human Health Risk Assessment for Groundwater Work Plan**, Draft, Former Plum Brook Ordnance Works, January.

Shaw Environmental, Inc. (Shaw), 2005, **2004 Data Summary and Evaluation Report**, Final, Former Plum Brook Ordnance Works, April.

Table 1			
Summary and Recommendations for the BHHRA Groundwater Data Set			
Overburden Wells			
Well ID	Recommendation^a	Size of Resulting Data Set^b	Direction of Potential Bias^c
<i>TNT Area A</i>			
TNTA-MW10	Use all unfiltered samples	3 (bailer)	None apparent
TNTA-MW11*	Eliminate 2001 unfiltered sample	3 (bailer)	None apparent
MK-MW22*	Use all unfiltered samples	2 (bailer)	None apparent
MK-MW23*	Use all unfiltered samples	2 (bailer)	High
MK-MW24	Use all unfiltered samples	11 (2 bailer; 9 low flow)	None apparent
<i>TNT Area B</i>			
MK-MW17	Use all unfiltered samples	5 (3 bailer; 2 low flow)	None apparent
<i>TNA Area C</i>			
TNTC-MW03*	Eliminate 1998 unfiltered sample	2 (bailer)	None apparent
TNTC-MW04*	Use all unfiltered samples	4 (bailer)	None apparent
TNTC-MW05	Use all unfiltered samples	4 (bailer)	None apparent
TNTC-MW06	Use all unfiltered samples	2 (bailer)	None apparent
IT-MW09*	Use all unfiltered samples	2 (bailer)	High
<i>Pentolite Road Red Water Pond Area</i>			
IT-MW05*	Use all unfiltered samples	2 (bailer)	High
PR-MW07*	Use all unfiltered samples	2 (bailer)	None apparent
PR-MW08*	Use all unfiltered samples	2 (bailer)	None apparent
PR-MW09*	Use all unfiltered samples	2 (bailer)	Low ^e
<i>West Area Red Water Pond Area</i>			
PB-WA-MW01	Use all unfiltered samples	2 (bailer)	None apparent
PB-WA-MW02*	Use all unfiltered samples	2 (bailer)	High ^f
IT-MW02	Use all unfiltered samples	2 (bailer)	None apparent
IT-MW10*	Use 1997 unfiltered and 1998 filtered sample	2 (bailer)	Low ^d
Bedrock Wells			
Well ID	Recommendation^a	Size of Resulting Data Set^b	Direction of Potential Bias^c
<i>TNT Area A</i>			
BED-MW18	Use all unfiltered samples	4 (2 bailer; 2 low flow)	None apparent
TNTA-BEDGW-001	Use all unfiltered samples	2 (bailer)	None apparent
<i>TNT Area B</i>			
TNTB-BEDGW-001	Use all unfiltered samples	4 (2bailer; 2 low flow)	None apparent
TNTB-BEDGW-003*	Use all unfiltered samples	2 (bailer)	High
TNTB-BEDGW-004	Use all unfiltered samples	2 (low flow)	None apparent
<i>TNTC Area C</i>			
TNTC-BEDGW-001	Use all unfiltered samples	2 (low flow)	None apparent
BED-MW13*	Use all unfiltered samples	4 (bailer)	None apparent
<i>Pentolite Road Red Water Pond Area</i>			
BED-MW15	Use all unfiltered samples	4 (bailer)	None apparent
BED-MW-23	Use all unfiltered samples	2 (1 bailer; 1 low flow)	None apparent
<i>West Area Red Water Ponds Area</i>			
BED-MW14*	Use filtered 1997 sample	4 (2 bailer; 2 low flow)	Low ^d

Bedrock Wells (cont'd)			
Well ID	Recommendation^a	Size of Resulting Data Set^b	Direction of Potential Bias^c
<i>Downgradient Boundary Wells</i>			
BED-MW17*	Use all unfiltered samples	6 (2 bailer; 4 low flow)	None apparent
BED-MW19	Use all unfiltered samples	6 (2 bailer; 4 low flow)	None apparent
BED-MW22	Use all unfiltered samples	4 (low flow)	None apparent
BED-MW24*	Eliminate July 2002 sample	9 (1 bailer; 8 low flow)	None apparent
BED-MW27	Use all unfiltered samples	3 (bailer)	None apparent
BED-MW30	Use all unfiltered samples	2 (low flow)	None apparent

^a The default position is to use all unfiltered samples. Reasons for differing from the default are substantially high concentrations that accompany high turbidity measurements. See text for details.

^b Sample collection method(s) shown in parentheses.

^c See text for details.

^d Use of the unfiltered data was judged as nonrepresentative would have introduced an unnecessarily high bias. The filtered data are recommended because: 1) they were generally consistent with the remaining unfiltered data and whatever low bias their inclusion brings is minimal, and 2) exclusion of the filtered sample would have severely limited the size and, thus, representativeness of the data set.

^e The 1997 data set appears to be anomalously low. However, this determination cannot be definitively made because only two samples were collected from this well.

^f Samples had very high turbidity. The 1998 filtered sample yielded similar analytical results, but the 1997 filtered sample did not. Thus, the high bias is regarded as possible but not likely.

Note: Each well marked with an asterisk had at least one sample with a turbidity reading exceeding 150 NTU and was, thus, specifically evaluated in this review.

**RESPONSE TO COMMENTS ON PREVIOUS VERSIONS
OF THE WORK PLAN**

Responses to Comments
Technical Memorandum
“Use of Groundwater Analytical Data in the
Groundwater Baseline Human Health Risk Assessment”
Plum Brook Ordnance Works, Sandusky, Ohio,
May 23, 2005

The May 23, 2005 Technical Memorandum was written in response to OEPA Comment No. 1 on the January 31, 2005 Baseline Human Health Risk Assessment for Groundwater (BHHRA) Work Plan. These Comments on the BHHRA Work Plan were sent to the U.S. Army Corps of Engineers (USACE) Nashville District on March 3, 2005. Note that these responses were approved by the Ohio Environmental Protection Agency (OEPA) during the September 15, 2005 team meeting at Sandusky, Ohio.

Comments by OEPA, Division of Emergency and Remedial Response (DERR) on the Technical Memorandum.

Reviewer: Ron Nabors

Ohio EPA has reviewed the technical memorandum and corresponding ground water dataset evaluation and have the following comments. For clarification, the shallow overburden saturated zone will not be quantitatively evaluated in the baseline human health risk assessment; only the bedrock (shale/carbonate) zone.

Comment 1a: **Filtered and unfiltered ground water analytical results should not be pooled into one dataset for the purpose of developing a ground water exposure point concentration (EPC). The two types of data are inherently different due to sample collection techniques (i.e., use of a 0.45 micron filter) and potential differences in exposures to receptors (e.g., filtered ingestion of ground water by an adult and unfiltered dermal contact by a construction worker). USACE/Shaw should develop ground water datasets at each well that are comprised totally of unfiltered ground water analytical results for use in the risk assessment.**

Response 1a: It is recognized that low-flow sampling is generally regarded as superior to a bailer method because of the turbidity that may be generated through use of a bailer. We also recognize that unfiltered analytical data are generally preferable, unless excessive turbidity associated with the sampling method is encountered. That is why the second bullet on page 2-2 of the Work Plan recommended that filtered bailer data be used rather than unfiltered as a starting point, and that the unfiltered bailer data be considered if the filtered bailer concentrations are obviously less than the unfiltered low-flow concentrations. OEPA responded with the excellent suggestion that a table be developed to compare data so that all team members can agree on a data set prior to performing risk calculations. The Technical Memorandum and accompanying tables were prepared responsive to the OEPA suggestion.

There was apparently a miscommunication between USACE/Shaw and OEPA on the issue of combining data. USACE/Shaw did not understand the OEPA comment to indicate that filtered data could not be combined with unfiltered data under any circumstance, but rather that the data should be evaluated individually to make this determination. The conclusions of the Technical Memorandum recommended the inclusion of only two filtered samples in the BHHRA. These are the 1998 filtered sample from IT-MW10 and the 1997 filtered sample from BED-MW14. The Technical Memorandum well-by-well comparison gives the reasoning behind these recommendations.

Based on OEPA Comment No. 1a on the Technical Memorandum, USACE/Shaw will remove the unfiltered samples from IT-MW10 collected in 1998 and the unfiltered sample from BED-MW14 collected in 1997 without replacement by the associated filtered samples.

Comment 1b: **Ohio EPA is amenable with pooling unfiltered ground water analytical results collected using bailer and low-flow sampling techniques. Ohio EPA supports this decision due to the fact that many of the wells (both overburden and bedrock) display minimal recharge thus prohibiting the use of low-flow sampling techniques. The amount of time, funding, and other resources necessary to collect a database entirely of unfiltered low-flow ground water analytical results at each area of concern does not appear to be justified for the purposes of the sitewide ground water investigation (GWI) at the NASA Plum Brook Station (NPBS).**

Response 1b: Comment noted.

Comment 1c: **Ohio EPA is unclear as to why the shallow overburden saturated zone will not be quantitatively evaluated in the risk assessment. Ohio EPA requests that Shaw provide them with the rationale for excluding this zone from the (*sic*).**

Response 1c: Groundwater in the overburden is very continuous and seasonal. During the 2001 groundwater remedial investigation the installation of 135 temporary piezometers were planned. After the installation of only 32 piezometers, the USACE and OEPA agreed that further installation of temporary overburden piezometers was not required because of a paucity of groundwater. Note that groundwater was encountered during drilling in only 1 (TNTA-GW21) of the 32 piezometers that were installed. After letting the temporary piezometers stand for up to 7 days, 26 of these wells were dry and 1 piezometer had only a few inches of water in it (TNTB-GW02).

Even though perched groundwater is present in some areas and potentially could be contacted by construction workers, such exposure would be limited. The limited extent and seasonality of the groundwater would result in any groundwater exposure to be of a very short term. Because of the temperature conductance of water and the temperate climate of northern Ohio, a worker would not be expected to have prolonged contact with water during most of

the year. The majority of the warmer months, when worker contact would otherwise be more plausible, are dry months (e.g., July, August, September) at PBOW when little water would typically be expected in the overburden. Generally, at PBOW the water table is several feet below ground surface, even during wet months. Therefore, because of safety concerns (i.e., wall collapse) at these depths, it is expected that time spent in an excavation, where groundwater may be present, would be minimal. Any exposure to site-related chemicals via groundwater contact (if present) would be accordingly minimal in comparison to risks associated with direct contact of site soils.

Based on potential site-related human health risks associated with direct contact with soil, soil removal and remediation has largely been completed at TNTB and the Pentolite Road Red Water Pond Area, and is planned for TNTA and TNTC. Such removal and remediation is being performed following the site health and safety plan to minimize human health risks. Removal of the soil represents a removal of a potential source to groundwater contamination in the overburden groundwater where it exists. Thus, post-remediation contact with overburden groundwater should minimize risks even further. Analytical results from the overburden groundwater are being used in a site-wide groundwater transport model to determine the potential impact of site-related chemicals in the overburden groundwater on future concentrations in the bedrock aquifer.

Comment 1d: **In summary, Ohio EPA is amenable with the ground water datasets proposed in the technical memorandum with the modifications noted in items a. and b. above.**

Response 1d: See responses to 1a and 1b.

Comment 2a: **Once the ground water datasets for each well have been established, Ohio EPA is unclear as to how the datasets will be used in the risk assessment. For example, will a statistical upper confidence limit be developed for each well at each area of concern (AOC) for use as a ground water exposure point concentration (EPC)?**

Response 2a: Sufficient data are not available to perform a statistical evaluation at each well.

Comment 2b: **Will the datasets for all the wells at a particular AOC be pooled to calculate a single statistical value for use as an EPC?**

Response 2b: Section 3.2.1 of the Work Plan states that a 95th percent upper confidence limit on the mean will be calculated for each data set having at least five samples. This protocol is the same as that used for previous human health risk assessments and work plans associated with PBOW (IT Corporation, 1998a,b; 2000a,b; 2001). For groundwater, there are no identified plumes, so the USACE considers it appropriate to pool all of the data for each AOC; for the overburden, this includes both monitoring well and direct-push results for

organics. As stated in the Work Plan, the overburden and bedrock units will be evaluated separately.

Comment 2c: Will a maximum contaminant concentration or a statistical upper confidence limit be used as an EPC at each well, whichever is higher, or will the corresponding EPC be obtained from pooling all data from all wells at a particular AOC?

Response 2c: As stated in the response to Comment No. 2b., it is the intention of the USACE to pool all appropriate data for each water bearing unit.

Comments 2d: Is the risk assessment going to be completed at each well individually at each AOC or will the wells be 'pooled' in some manner as to evaluate each AOC as a whole?

Response 2d: The risk assessment will be based on the EPC of the pooled data of all appropriate analytical data for each AOC. This EPC will either be a UCL of the arithmetic mean concentration or the maximum detected concentration, whichever is lower.

Comment 2e: How will the risk associated with the downgradient boundary wells be compared or evaluated against the risk associated with the AOCs located further upgradient at the NPBS?

Response 2e: The Scope of Work for the groundwater risk assessment includes a single evaluation of all combined downgradient locations to determine whether the potential exists for adverse human health effects at any downgradient well. The Work Plan will be revised to specify that the maximum detected concentrations will be used in the determination of the EPCs for the downgradient wells.

Comment 2f: The items noted above (i.e., 2a through 2 e) should be clarified in some form of sitewide GWI risk assessment work plan.

Response 2f: Based on the contract between Shaw and the USACE, the current Work Plan pertains only to the three TNT manufacturing, the two red water pond areas, and wells downgradient of these areas at the facility boundary.

Comment 3: For reference, Ohio EPA has developed an approach for the calculation of ground water EPCs for use in risk assessments for portions of facilities subject to the requirements of a RCRA/Ohio EPA Division of Hazardous Waste Management closure. The EPC is calculated using the 95% upper confidence limit (UCL) of the mean where the dataset consists of 12 samples from three monitoring wells over four quarters of sampling at each well. These wells should be located within the center of the contaminant plume. If less than 3 wells are contaminated, then the maximum concentration (taken from the well with the highest concentration of the contaminant) should be used as the ground water

EPC. If the maximum contaminant concentration is lower than the 95% UCL, then the maximum contaminant concentration should be used as the EPC.

For inorganic constituents of concern (COCs), the type of ground water data (filtered vs. unfiltered) to be used in the risk assessment is based upon an evaluation of turbidity. If the turbidity of the ground water can be reduced to a level below 5 nephelometric turbidity units (NTUs) by using low flow purging and sampling techniques, then the inorganic background database shall consist of total metals results. If the turbidity of the shallow ground water cannot be reduced to a level below 5 NTUs, then the facility may generate an inorganic background database based upon filtered metals results.

Response 3:

Each organic compound with a maximum detected concentration (MDC) exceeding the U.S. Environmental Protection Agency Region 9 Preliminary Remediation Goal (PRG) for tap water (EPA, 2004), based on a hazard quotient of 0.1 or incremental lifetime cancer risk of 1 by 10^{-6} (whichever results in a lower concentration), will be selected as a chemical of potential concern (COPC). Groundwater risks associated with each organic COPC in the BHHRA will be based on the exposure point concentration (EPC). Either the 95th percent upper confidence limit of the arithmetic mean (UCL) or the maximum detected concentration (MDC) of the data set, whichever is less, will represent the EPC for that COPC. Consistent with the human health risks assessments performed for other media at TNTA, TNTB, TNTC, and the Red Water Pond Areas, the MDC will be used as the EPC for all data sets with fewer than five samples.

For the BHHRA, only unfiltered groundwater data will be evaluated. Groundwater risks associated with inorganics will be assessed as described above for organic compounds, except that the MDC of each unfiltered inorganic will also be screened against the background screening concentration (BSC) (Shaw, 2005). Only an inorganic whose MDC exceeds the BSC will be further evaluated in the BHHRA.

With respect to the first paragraph of Comment No. 3, quarterly sampling was not performed in any of the former TNT or red water pond areas. A brief review of the nitroaromatics analytical results reveals no plumes in bedrock groundwater among the TNT manufacturing areas and the red water pond areas. With respect to the overburden, either no plume is apparent or too few wells are present to identify a plume (e.g., only one overburden well is present in TNTB). It is also noted that groundwater may be too intermittent in the overburden to identify a plume.

In addition to monitoring wells, groundwater samples were collected from temporary piezometers that were installed using direct-push technology. With respect to organics in overburden groundwater, one-time samples have been collected from numerous temporary piezometers. For organics, the USACE

plans to use these along with the monitoring well samples for risk evaluation. Note that because only a qualitative screening evaluation is planned for overburden groundwater, the MDC for each organic analyte would be used in the screening evaluation.

The second paragraph of Comment No. 3 presents the possibility of screening filtered site data against filtered background data for those unfiltered samples or wells in which NTU readings cannot be reduced to a value below 5 NTUs. The USACE will consider screening of filtered site data against filtered background data, as appropriate, in the uncertainties analysis. For instance, if the MDC of unfiltered arsenic were to exceed the BSC and PRG, arsenic would be carried through the risk assessment. However, if it were shown that the observed concentrations of arsenic in unfiltered groundwater were associated with excessive turbidity (based on a comparison of filtered data for the site versus the filtered data for the background samples), then it might be stated that, in this case, arsenic is unlikely to be truly site related and should not be regarded as a COC.

Comment 4: **Shaw should be preparing responses to the remainder of the Ohio EPA letter dated March 3, 2005 on the January 2005 Baseline Human Health Risk Assessment for Groundwater Work Plan for submittal and review by the agency.**

Response 4: Shaw has prepared responses to the remainder of the March 3, 2003 letter. These are included in this same submittal.