# Pioneer AOC Updated Human Health Risk Assessment, Former Wilkins Air Force Station, Shelby, Ohio

PREPARED FOR: USACE Louisville District

PREPARED BY: CH2M HILL

DATE: February 8, 2012

## Introduction

Wilkins Air Force Station (AFS) is a formerly used defense site (FUDS) in Shelby, Ohio (Figure 1). The 486-acre site was acquired by the U.S. Air Force in 1943 for use as a storage depot for medical supplies, airplane parts, clothing, rations, vehicle parts, and supplies. In 1960, the U.S. Air Force declared the facility excess and closed it in June 1961. Portions of the former AFS were sold, and the current land use is as an industrial business complex and an educational facility.

The Pioneer Area of Concern (AOC) is the focus of this investigation. Figure 2 shows the location of Pioneer AOC at the former AFS. The Pioneer AOC is on the western portion of the Pioneer Career and Technology Center (PCTC) property (Figure 2).

The Pioneer AOC initially was investigated during a preliminary assessment (Plexus Scientific Corporation [Plexus] 2000) to characterize the nature and extent of contamination associated with fill material within the AOC and, in addition, to establish background levels of chemicals in soil and groundwater in the area of the former AFS. A site investigation (Plexus 2001) and remedial investigation (RI; Plexus 2006) were conducted to further assess relative risk to potential receptors of chemicals of potential concern (COPCs). The RI determined that levels of contamination present within soil of the Pioneer AOC are acceptable for the current use (commercial/industrial); however, under a future hypothetical residential use scenario, levels of soil contamination present would not be acceptable, and groundwater data were not sufficient to determine if the contaminants present were naturally occurring or site-related.

Between October 2008 and July 2009, CH2M HILL completed a supplemental RI of the Pioneer AOC. The supplemental RI was conducted to determine whether levels of arsenic, manganese, and thallium present in groundwater at the Pioneer AOC are naturally occurring or site-related. During this investigation, CH2M HILL conducted four rounds of additional groundwater sampling from three monitoring wells within the AOC and from two upgradient background monitoring wells. The RI addendum (CH2M HILL 2011a) included a direct and statistical comparison of the quarterly groundwater data to the background data. Based on the comparisons, the RI addendum concluded that concentrations of arsenic and thallium in the AOC wells appear to be naturally occurring in groundwater. Concentrations of manganese in groundwater at well one well location (MW-08) appear to be elevated above what is naturally occurring.

The former AFS has been zoned heavy industrial for many years, and it is the most reasonable expected use in the future. No future construction is planned for the western side of the campus near the AOC. Construction of buildings or other structures over the AOC in the future also will be constrained by the geotechnical, permitting, and building design challenges of building on a landfill. Any future buildings near the AOC would be connected to the local municipal water supply, thereby eliminating exposure to groundwater via drinking water. Therefore, the RI (Plexus 2006) concluded the groundwater pathway was incomplete and was not assessed. The cancer risks and noncancer hazards estimated in the RI (Plexus 2006) for soil exposure scenarios for the site worker, trespasser, and construction worker soil exposure scenarios were at or below U.S. Environmental Protection Agency (USEPA) target levels. Overall, potential exposures under the industrial land use scenario do not pose a human health risk based on the original RI (Plexus 2006). Future residential use is not planned for the AOC; however, the cancer risks and noncancer hazards estimated in the RI (Plexus 2006) for hypothetical residential use exceed USEPA target levels.

The RI addendum (CH2M HILL 2011a) included a revised assessment of the construction worker risks from exposure to soil at the Pioneer AOC with site-specific information and corrected toxicity information for two constituents (manganese and mercury) that were transposed in the RI (Plexus 2006) risk assessment. The RI addendum confirmed no unacceptable risk for a construction worker exposed to site soil (CH2M HILL 2011a).

Because the 2006 risk assessment at Pioneer AOC did not address the groundwater pathway and manganese concentrations in groundwater exceed background levels, a risk assessment of the groundwater pathway was recommended to adequately evaluate the construction worker potentially exposed to soil and groundwater.

Based on communications with the Ohio Environmental Protection Agency (Ohio EPA), including September 17, 2010 comments on the RI addendum and a July 5, 2011 meeting, the scope of this updated human health risk assessment (HHRA) is to assess the potential risk to human health from exposure to groundwater at Pioneer AOC and to combine soil risk results from the RI risk assessment (Plexus 2006) and updated construction worker soil results from the RI addendum (CH2M HILL 2011a) to provide cumulative risks for potential receptor populations (trespasser, site worker, industrial worker, construction worker, and resident) at the AOC. During the meeting on July 5, 2011, Ohio EPA representatives suggested the Pioneer AOC updated HHRA follow the approach of the Shelby Horizons AOC HHRA (CH2M HILL 2011b) by including an industrial worker. It was noted that industrial worker exposure pathway previously was not included in the RI HHRA (Plexus 2006). The industrial worker scenario in the Shelby Horizons AOC HHRA only included an evaluation of ingestion of, dermal contact with, and inhalation of volatile and particulate emissions from surface soil because groundwater use for industrial purposes does not currently and is not anticipated to occur in the future. The same is expected for the Pioneer AOC; therefore, only the groundwater ingestion exposure pathway for the industrial worker scenario was included in this risk assessment for informational purposes. This updated HHRA was conducted in accordance with the approach used in the Shelby Horizons AOC RI (CH2M HILL 2011b).

# Scope of Risk Assessment

The primary objective of this updated HHRA is to assess potential health risks associated with exposure to site soil and groundwater under current and potential future site conditions. The risk assessment consists of the following components:

- Data Evaluation and Identification of COPCs—Identification of the constituents found onsite and selection of the COPCs. COPCs identified in this screening are the focus of the subsequent evaluation in the risk assessment.
- Exposure Assessment— Identification of the potential pathways of human exposure, characterization of the potentially exposed populations, and estimation of the magnitude, frequency, and duration of exposures.
- Toxicity Assessment—Assessment of the potential adverse effects of the COPCs and compilation of the toxicity values used for developing numerical risk estimates.
- Risk Characterization—Integration of the results of the exposure assessment and toxicity assessment to develop numerical estimates of health risks.
- Uncertainty Assessment— Identification and discussion of sources of uncertainty associated with the data, methodology, and values used in the risk assessment.

These components are described briefly in the following sections.

The HHRA incorporates the general methodology described in the following guidance sources:

- *Risk Assessment Guidance for Superfund* [RAGS], *Volume 1, Human Health Evaluation Manual, Part A* (USEPA 1989)
- *Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual, Supplemental Guidance, Standard Default Exposure Factors* (USEPA 1991)
- *Soil Screening Guidance: User Guide* (USEPA 1996)
- *Exposure Factors Handbook* (USEPA 1997a)
- *Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual, Part D* (USEPA 2001)
- *Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual, Part E – Supplemental Guidance for Dermal Risk Assessment* (USEPA 2004a)
- *Assessing Compounds without Formal Toxicity Values Available for Use in Human Health Risk Assessment* (Ohio EPA 2005)
- *Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual, Part F – Supplemental Guidance for Inhalation Risk Assessment* (USEPA 2009a)
- Integrated Risk Information System (IRIS; USEPA 2009b)

The supporting tables for this HHRA are presented in RAGS Part D format (USEPA 2001) in the attachment.

## Data Evaluation and Identification of COPCs

The data evaluated in the updated HHRA for groundwater exposure pathways consist of groundwater samples collected during RI (Plexus 2006) and RI addendum (CH2M HILL 2011a) activities conducted at the site. Groundwater sample analyses include volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), and metals (dissolved and total) in groundwater collected in 2003 to support the RI (Plexus 2006), and for dissolved metals (arsenic, manganese, and thallium) in groundwater collected between October 2008 and July 2009 (CH2M HILL 2011a). The most recent groundwater data were used for each chemical for each of the three monitoring wells (MW-05, MW-06, and MW-08) and from the two upgradient background monitoring wells (BG-01 and BG-02). The quarterly groundwater data for dissolved metals (arsenic, manganese, and thallium) collected from October 2008 through July 2009 did not demonstrate significant variation, with less than one order of magnitude difference across the sampling events (Table 1); therefore, the most recent quarterly data (July 2009) were used for these dissolved metals.

Table 2 presents the samples locations and analytical parameters that were evaluated in this updated HHRA. The following bullets discuss how the qualified data were evaluated in the risk assessment:

- Data qualified with a J (estimated) were treated as detected concentrations.
- Data qualified with an R (rejected) were excluded from the risk assessment. These include data that did not meet the goal for completeness (the percentage of valid or usable measurements compared to planned measurements).
- Data qualified with a B (blank contamination) were used in the risk assessment as if these constituents were not detected.
- For duplicate samples, the greater of the two concentrations was used as the sample concentration in calculating exposure point concentrations (EPCs; USEPA 2002).
- One-half the reporting limit was used to determine COPC status, for analytes that were not detected. Following identification as a COPC, the analyte reporting limit was used in calculating EPCs.

The HHRA dataset was screened to select COPCs using the following the procedures.

- The maximum detected concentrations in groundwater were compared with USEPA Region 9 preliminary remediation goals (PRGs) for tap water (USEPA 2004b). Constituents with maximum detected concentrations greater than the PRGs were selected as COPCs. Tap water PRGs based on noncarcinogenic effects were adjusted (divided by 10) to account for exposure to multiple constituents. PRGs based on carcinogenic effects were used as presented in the PRG table. Under Ohio EPA’s direction, groundwater data were compared with the regional screening levels (RSLs) for tap water, adjusted as described above (USEPA 2011), for comparative purposes only.

- Constituents considered essential nutrients, present at low concentrations (that is, only slightly elevated above naturally occurring levels), and toxic only at very high doses were eliminated from the quantitative risk analysis. These constituents include calcium, magnesium, phosphorous, potassium, and sodium. Although iron also is considered an essential nutrient and is toxic at only very high doses, iron was selected as a COPC because a provisional toxicity value is available.

The maximum detected concentration of each constituent in groundwater was compared to the criteria discussed above to select the COPCs. If the maximum detected concentration exceeded the criteria, the constituent was selected as a COPC. Additionally, for constituents that were not detected, one-half the reporting limit was compared to the screening criteria to identify COPCs for quantitative evaluation in the HHRA. Groundwater results indicated VOCs and SVOCs were not detected sitewide in groundwater, with the exception of single detections at MW-05 of estimated concentrations between the detection limit and the reporting limit (J-flag in the attachment, Table 2.1) of acetone, carbon disulfide, naphthalene, and phenanthrene. Therefore, only nondetect total metals and nondetect dissolved metals were identified as COPCs for quantitative evaluation in the HHRA when one-half the reporting limit was above the screening level. Dissolved and total metals were evaluated because it is likely the metals concentrations in a developed potable water supply well would more closely resemble the dissolved (filtered) metals data than the total metals data, and thus, use of the total metals data may overestimate any risks associated with use of groundwater as a potable water supply. Therefore, dissolved metals data for groundwater were used to evaluate ingestion of potable drinking water pathway for the future resident and future industrial worker receptor populations.

The results of the COPC screening are presented in the attachment, Table 2.1.

Table 3 identifies the constituents that were selected as COPCs for groundwater. Twelve total metals (aluminum, antimony, arsenic, barium, cadmium, chromium, iron, lead, manganese, nickel, thallium, and vanadium) were selected as COPCs. The same dissolved metals were identified as COPCs with the exception of chromium, lead, and nickel. Maximum detected total and dissolved metals concentrations in the dataset evaluated for monitoring wells MW-05, MW-06, and MW-08 were above the detected total and dissolved metals in background wells BG-01 and BG-02. No VOCs were identified as groundwater COPCs; therefore, no inhalation exposure pathways were evaluated in this HHRA for groundwater.

Fewer than five samples were available for groundwater; therefore, the maximum detected concentrations of the COPCs in the dataset evaluated for monitoring wells MW-05, MW-06, and MW-08 were used as the reasonable maximum exposure (RME) EPCs (Table 3.1.RME in the attachment). For nondetect total metals and nondetect dissolved metals identified as COPCs, the analyte reporting limit was used as the RME EPC to calculate risks. When groundwater exposure pathways indicated potential risks above USEPA target cancer risk level of $1 \times 10^{-4}$ and noncancer hazard of 1, central tendency exposure (CTE) risks were calculated for qualitative discussion in the uncertainty assessment. The average concentrations of detected concentrations and reporting limit values were used as the CTE EPCs.

## Exposure Assessment

Exposure assessment is the estimation of the likelihood, magnitude, frequency, duration, and routes of exposure to a constituent. "Exposure" refers to the potential contact of an individual (or receptor) with a constituent. Exposure can occur when constituents migrate from a source to an exposure point, or when a receptor comes into direct contact with contaminated media.

This HHRA evaluates groundwater exposure pathways for potential receptor populations identified in the RI HHRA (Plexus 2006). The Pioneer AOC is not currently or anticipated to be used for residential purposes; however, a residential soil exposure scenario was included in the RI risk assessment (Plexus 2006) to determine an upper bound on the level of risk posed by the site. Additionally, the groundwater use patterns are already established for the Pioneer AOC, and the use of site groundwater for industrial or residential purposes is unlikely. Drinking water is supplied by the Shelby Water Department, which draws from two surface water reservoirs and has two water supply wells for backup. The two reservoirs store an approximate 1-year supply of water (Shelby Municipal Utilities 2009). The Pioneer AOC backup water supply wells are approximately 30 feet in diameter and 45 feet deep. The backup water supply wells are screened at a deeper interval than where the uppermost groundwater is encountered at approximately 10 feet below ground surface (bgs; Plexus 2006). Therefore, it is unlikely that onsite workers or hypothetical onsite residents would be exposed to shallow groundwater through ingestion as drinking water, dermal contact, or inhalation of contaminants during regular activities. However, a potable use scenario is included in this risk assessment to support the upper bound evaluation of risk posed by the site.

Generally, it is assumed that construction workers may contact groundwater that is present at 10 feet bgs or less. The general depth to the uppermost groundwater unit at the Pioneer AOC is approximately 10 feet bgs. Therefore, construction workers could be exposed to the shallow groundwater during construction activities, and an evaluation of potential construction worker exposures is included in this risk assessment.

Potential groundwater exposure pathways and scenarios that were evaluated in this HHRA include:

- Construction workers: Exposure to groundwater through dermal contact with and inhalation of volatile emissions from shallow groundwater encountered during construction activities (if detected)
- Residents (adult, child, and lifetime): Exposure to groundwater through ingestion, dermal contact, and inhalation of volatile emissions during potable water use (if detected)
- Industrial workers: Exposure to groundwater through ingestion

### Estimation of Constituent Intakes

Intake is the amount of a constituent entering the exposed receptor's body. Intakes of COPCs through contact with exposure media, such as incidental ingestion and dermal contact with groundwater, are expressed using algorithms provided in USEPA guidance

(USEPA 1989, 2004a). The algorithms for estimating intakes of COPCs for individual exposure pathways are provided below.

### Incidental Ingestion of Groundwater

The equation to calculate intake from the incidental ingestion of soil can be expressed as:

$$CDI\ (mg/kg - day) = \frac{CW\ x\ IR_w\ x\ EF\ x\ ED\ x\ CF}{BW\ x\ AT}$$

Where:

- $CDI$ = chronic daily intake (milligrams per kilogram per day [mg/kg-day])
- $CW$ = constituent concentration in groundwater (micrograms per liter [µg/L])
- $IR_w$ = ingestion rate of water (liters per day [L/day])
- $EF$ = exposure frequency (days per year)
- $ED$ = exposure duration (years)
- $CF$ = conversion factor (0.001 milligrams per microgram [mg/µg])
- $BW$ = body weight of exposed individual (kilograms [kg])
- $AT$ = averaging time, or period over which exposure is averaged (days)

### Dermal Contact with Groundwater

The methods presented in RAGS Part E (USEPA 2004a) were used to evaluate dermal exposure to groundwater for construction worker receptors.

The dose from dermal contact with groundwater can be estimated from the following equations:

$$DAD\ (mg/kg - day) = \frac{DA_{event}\ x\ SA\ x\ EV\ x\ EF\ x\ ED}{BW\ x\ AT}$$

Where:

- $DAD$ = dermal absorbed dose (mg/kg-day)
- $DA_{event}$ = dermally absorbed dose per event (milligrams per square centimeter per event [mg/$cm^2$-event])
- $SA$ = skin surface area available for contact (square centimeter [$cm^2$])
- $EV$ = event frequency (events per year)
- $EF$ = exposure frequency (days per year)
- $ED$ = exposure duration (years)
- $BW$ = body weight of exposed individual (kg)
- $AT$ = averaging time, or period over which exposure is averaged (days)

1. $DA_{event}$ for Inorganics:

$$DA_{event}\ (mg/cm^2 - event) = CW\ x\ K_p\ x\ t_{event}\ x\ 0.001\ {}^{mg}\!/_{\mu g}\ x\ 0.001\ {}^{L}\!/_{cm^3}$$

Where:

- $DA_{event}$ = dermally absorbed dose per event (mg/$cm^2$-event)

$CW$ = constituent concentration in groundwater (µg/L)
$K_p$ = permeability coefficient (centimeters per hour [cm/hr]; chemical-specific)
$t_{event}$ = event duration (hours per event)

2. $DA_{event}$ for Organics:

For $t_{event} \le t^*$:

$$DA_{event}\ (mg/cm^2 - event) = 2\ x\ FA\ x\ CW\ x\ K_p \sqrt{\frac{6\,\tau_{event}\ x\ t_{event}}{\pi}}$$

Where:

$DA_{event}$ = dermally absorbed dose per event (mg/cm²-event)
$CW$ = constituent concentration in groundwater (µg/L)
$FA$ = fraction absorbed water (dimensionless; chemical-specific)
$K_p$ = permeability coefficient (cm/hr; chemical-specific)
$\tau_{event}$ = lag time per event (hours per event; chemical-specific)
$t_{event}$ = event duration (hours per event)

For $t_{event} > t^*$:

$$DA_{event}\ (mg/cm^2 - event) = FA\ x\ CW\ x\ K_p \left[\frac{t_{event}}{1+B} + 2\,\tau_{event}\left(\frac{1+3B+3B^2}{(1+B)^2}\right)\right]$$

Where:

$DA_{event}$ = dermally absorbed dose per event (mg/cm²-event)
$CW$ = constituent concentration in groundwater (µg/L)
$FA$ = fraction absorbed water (dimensionless; chemical-specific)
$K_p$ = permeability coefficient (cm/hr; chemical-specific)
B = ratio of permeability coefficient of compound through the stratum corneum relative to its permeability coefficient across the viable epidermis (dimensionless; chemical-specific)
$\tau_{event}$ = lag time per event (hours per event; chemical-specific)
$t_{event}$ = event duration (hours per event)

The intake equation requires exposure parameters specific to each exposure pathway. Many of the exposure parameters have default values, which were used for this assessment. These assumptions, based on estimates of body weights, media intake levels, and exposure frequencies and duration, are provided in USEPA guidance. Table 4.1.RME in the attachment identifies the exposure parameters and intake equations for each scenario evaluated in the risk assessment.

The methods presented in RAGS Part E (USEPA 2004a) for estimating dermal exposure to water were used to evaluate dermal exposure to groundwater for construction workers. The models for groundwater are shown in Table 4.1.RME in the attachment. Values for the chemical-specific parameters used in the models were obtained from the RAGS Part E (USEPA 2004a) and are presented in Table 7.1.RME Supplement A in the attachment.

## Toxicity Assessment

The toxicity assessment describes the relationship between the magnitude of exposure to a constituent and possible severity of adverse effects, and weighs the quality of available toxicological evidence. This assessment provides, where possible, a numerical estimate of the increased likelihood and/or severity of adverse effects associated with constituent exposure (USEPA 1989). The toxicity assessment identifies the toxicity values for the COPCs used in estimating potential health effects. Health effects are divided into two broad groups: noncarcinogenic and carcinogenic. This division of classification is because health risks are calculated differently for carcinogenic and noncarcinogenic effects, and separate toxicity values have been developed for carcinogenic and noncarcinogenic effects.

USEPA recommends that a tiered approach be used to obtain the toxicity values, the reference doses (RfDs) and cancer slope factors (CSFs), used to calculate noncancer and cancer risks, respectively (USEPA 2003a). The sources of toxicity values are as follows:

- Tier 1: USEPA's IRIS database (USEPA 2009b)
- Tier 2: Provisional Peer Reviewed Toxicity Value (PPRTV) database maintained by USEPA's National Center for Environmental Assessment (NCEA) and the Superfund Health Risk Technical Support Center
- Tier 3: Other USEPA and non-USEPA sources including NCEA, Agency for Toxic Substances and Disease Registry, Health Effects Assessment Summary Tables (USEPA 1997b), California Environmental Protection Agency, USEPA's Office of Water, and World Health Organization

The use of provisional toxicity values, such as those from the PPRTV database, increases the uncertainty of the quantitative risk estimate. If no toxicity values were available for a detected constituent, surrogate constituents were selected and their PRGs were used for the COPC selection process. Toxicity values consistent with those used in the HHRA presented in the RI (Plexus 2006) were used to calculate potential risks for groundwater and support cumulative risk estimates across the soil and groundwater exposure pathways for consistency in approach. Barium, cadmium, and iron noncancer toxicity information has changed since the HHRA in the RI (Plexus 2006); however, none of these COPCs was a significant risk driver in soil or groundwater.

### Toxicity Information for Noncarcinogenic Effects

Noncarcinogenic effects for oral and dermal exposure are quantified by comparing exposure or intake to RfDs. The RfD is a health-based criterion, expressed as constituent intake rate in units of mg/kg-day, used in evaluating noncarcinogenic effects. The RfD is based on the assumption that thresholds exist for certain toxic effects such as liver or kidney damage, but may not exist for other toxic effects such as carcinogenicity. In general, the RfD is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime of exposure (USEPA 1989). The RfD is used to evaluate adverse effects from the oral route of exposure.

Chronic RfDs are developed to evaluate potential toxicity for long-term exposure (more than 7 years of exposure). Subchronic RfDs are sometimes used to evaluate exposures of durations ranging from 2 weeks to 7 years, which may be more appropriate to address childhood (1 to 6 years) and construction worker (less than 1 year) exposure durations. Subchronic values generally are less available from data sources than other types of toxicity information. In the absence of an acceptable subchronic toxicity value, chronic values were used conservatively in the HHRA to evaluate exposure pathways.

### Toxicity Information for Carcinogenic Effects

Potential carcinogenic effects for oral and dermal exposures are quantified using oral CSFs. The CSF is defined as a plausible upper-bound estimate of the probability of a cancer effect per unit intake of a constituent over a lifetime (USEPA 1989). CSFs may be derived from the results of chronic animal bioassays, human epidemiological studies, or both. For carcinogens, risks are estimated as the probability that an individual will develop cancer over a lifetime because of exposure to the carcinogen. Cancer risk from exposure to contamination represents the anticipated excess or incremental cancer risk, which is cancer occurrence in addition to normally expected rates of cancer development over the average adult lifetime of 70 years.

### Estimated Toxicity Values for Dermal Exposure

Toxicity values have not been developed for the dermal absorption pathway. In general, the oral CSFs and oral RfDs are expressed as administered doses (that is, the amount of a constituent administered per unit time and weight). Conversely, exposures resulting from the dermal pathway are expressed as absorbed doses. Therefore, it is necessary to adjust the oral toxicity value to account for the chemical-specific absorption efficiency. Dermal toxicity values were derived from the oral toxicity values. Dermal RfDs and CSFs were estimated from oral toxicity values using chemical-specific gastrointestinal absorption factors ($ABS_{GI}$) to calculate total absorbed dose, as described in USEPA dermal risk assessment guidance (USEPA 2004a) using the equations shown below.

The dermal reference dose ($RfD_d$) is derived by multiplying the oral RfD by the $ABS_{GI}$:

$$RfD_d = RfD_o \times ABS_{GI}$$

Where:

| | | |
|---|---|---|
| $RfD_d$ | = | Dermal reference dose (mg/kg-day) |
| $RfD_o$ | = | Oral reference dose (mg/kg-day) |
| $ABS_{GI}$ | = | Fraction of constituent absorbed in the gastrointestinal tract (unitless) |

The dermal CSF ($CSF_d$) is derived by dividing the oral CSF by the $ABS_{GI}$:

$$CSF_d = \frac{CSF_o}{ABS_{GI}}$$

Where:

| | | |
|---|---|---|
| $CSF_d$ | = | Dermal cancer slope factor $(mg/kg\text{-}day)^{-1}$ |
| $CSF_o$ | = | Oral cancer slope factor $(mg/kg\text{-}day)^{-1}$ |
| $ABS_{GI}$ | = | Fraction of constituent absorbed in the gastrointestinal tract (unitless) |

The $ABS_{GI}$ values used in the HHRA were obtained from USEPA's *RAGS, Volume I: Human Health Evaluation Manual* (Part E, Supplemental Guidance for Dermal Risk Assessment) Final (USEPA 2004a). When chemical-specific $ABS_{GI}$ values are unavailable, a default $ABS_{GI}$ value of 1 for organic and inorganic chemicals (USEPA 2004a) was used. The dermal RfDs are included in Table 5.1 in the attachment. The dermal CSFs are presented in Table 6.1 in the attachment.

### Constituents without Available USEPA Toxicity Values

Some COPCs at the site may not have RfDs or CSFs because the noncarcinogenic and/or carcinogenic effects of these constituents are not yet determined. In these cases, toxicity values from a constituent with similar toxicological properties and approved toxicity values may be used as a surrogate. Surrogate chemicals with associated toxicity criteria were assigned to the other chemicals. The surrogates are identified in Table 2.1 in the attachment.

Lead, which was retained as a COPC for total groundwater, does not have available published toxicity factors. Lead is regulated by USEPA based on blood-lead uptake using a physiologically based pharmakokinetic model called the Integrated Exposure Uptake Biokinetic (IEUBK) Model. As a screening tool, lead is screened using the federal action level of 15 µg/L (USEPA 2009c). The maximum detected concentration of lead in site groundwater (43.1 µg/L) exceeded the groundwater screening level. Lead was not detected in the dissolved metals analyses (reporting limit of 10 µg/L) collected in 2003 to support the RI (Plexus 2006). Risks associated with lead in groundwater typically are evaluated for the resident using the IEUBK. The principal assumption associated with using the IEUBK model is that a child from 0 to 7 years old is the receptor for potential exposure to lead. The average lead concentration is used as the EPC in the IEUBK model.

The results of the IEUBK model for groundwater are shown in the attachment. The IEUBK evaluation resulted in a geometric average blood concentration of 2.6 micrograms per deciliter (µg/dL) of blood for children 0 to 7 years old. Approximately 0.3 percent of this population had a blood-lead level above USEPA's recommended level of 10 µg/dL. USEPA considers lead not to be a health concern if 95 percent of the population has a blood-lead level less than 10 µg/dL (USEPA 2003b). Therefore, lead in groundwater does not pose a health risk under residential use of the site. With the exception of the average lead groundwater concentration (21.03 µg/L) and the average soil lead concentration (45.2 mg/kg; Table 6-2 in the RI [Plexus 2006]), the default parameters associated with the IEUBK model were used in this evaluation (as shown in the attachment).

Risks for adult workers exposed to lead in groundwater were not quantitatively evaluated. The IEUBK model represents exposure to lead in groundwater under a potable use scenario. Results of the IEUBK evaluation indicate potable use of groundwater does not pose a health risk. Based on the limited exposure to groundwater that adult workers (industrial or construction workers) would have in comparison to residents, concentrations of lead in water would pose less risk for occupational exposures.

## Risk Characterization

Risk characterization combines the results of the previous elements of the risk assessment to evaluate the potential health risks associated with exposure to the COPCs. Potential human health risks are discussed independently for carcinogenic and noncarcinogenic constituents because of the different toxicological endpoints, relevant exposure duration, and methods used to characterize risk. Some constituents may produce both noncarcinogenic and carcinogenic effects, and were evaluated in both groups. The methodology used to estimate noncarcinogenic hazards and carcinogenic risks are described below. Following the description of the methodology, the noncarcinogenic hazards and carcinogenic risks for the site are discussed.

The results of the groundwater risk characterization are presented below by receptor. The risks are calculated in Tables 7.1.RME through 7.5.RME in the attachment. The risks are summarized in Tables 9.1.RME through 9.5.RME in the attachment. Tables 10.1.RME through 10.5.RME in the attachment show the receptor scenarios with a total hazard index (HI) greater than 1 and/or total carcinogenic risks greater than $1 \times 10^{-5}$. Constituents that contribute HIs greater than 0.1 or carcinogenic risks greater than $1 \times 10^{-6}$ are included in the tables. Cumulative risks across exposure pathways for soil and groundwater are presented in Table 4. The cumulative risks combine the groundwater risk results presented in Tables 9.1.RME through 9.5.RME in the attachment, with the soil risk results presented in Tables 6-29 and 6-30 for the site worker in the RI (Plexus 2006), Tables 6-35 and 6-36 for residential receptors in the RI (Plexus 2006), and Tables 9 and 10 of the RI addendum (CH2M HILL 2011a) for the construction worker. The HHRA for soil (0 to 10 feet bgs) presented in the RI evaluated a site worker scenario for site maintenance and grounds keeping in a maintained area that surrounds the mound area. The site worker scenario represents a site-specific exposure pathway that was based on discussions with staff from PCTC (Plexus 2006).

### Noncarcinogenic Hazard Estimation

Noncarcinogenic health risks are estimated by comparing the calculated intake to an RfD. The calculated intake divided by the RfD is equal to the hazard quotient (HQ):

$$HQ = Intake / RfD$$

The intake and RfD represent the same exposure period (that is, chronic or subchronic) and the same exposure route (that is, oral intakes are divided by oral RfDs). An HQ that exceeds 1 (that is, the intake exceeds the RfD) indicates there is a potential for adverse health effects associated with exposure to that constituent.

To assess the potential for noncarcinogenic health effects posed by exposure to multiple constituents, an HI approach is used (USEPA 1989). This approach assumes that noncarcinogenic hazards associated with exposure to more than one constituent are additive. Synergistic or antagonistic interactions between constituents are not considered. The HI may exceed 1 even if all of the individual HQs are less than 1. HIs also are added across exposure routes and media to estimate the total noncarcinogenic health effects to a receptor posed by exposure through multiple routes and media. An HI greater than 1 indicates there is some potential for adverse noncarcinogenic health effects associated with exposure to the constituents of concern. However, if the HI is greater than 1, it is possible to separate the HI by target organ/effect to determine if the HI for a specific target organ/effect is greater than 1. If the HI for each target organ/effect is not above 1, it can be assumed that there is no unacceptable noncarcinogenic hazard to the receptor.

### Carcinogenic Risk Estimation

The potential for carcinogenic effects due to exposure to site-related constituents is evaluated by estimating the excess lifetime carcinogenic risk (ELCR). ELCR is the excess incremental increase in the probability of developing cancer during one's lifetime because of the assumed exposures to the site over an individual's risks without exposure to the site.

Carcinogenic risk is calculated by multiplying the intake by the CSF.

$$ELCR = Intake \times CSF$$

The combined risk from exposure to multiple constituents was evaluated by adding the risks from individual constituents. Risks also were added across the exposure routes and media if an individual would be exposed through multiple routes and to multiple media.

When a cumulative carcinogenic risk to an individual receptor under the assumed RME exposure conditions at the site exceeds 100 in a million (that is, $10^{-4}$ excess carcinogenic risk), the Comprehensive Environmental Response, Compensation, and Liability Act generally requires remedial action to reduce risks at the site (USEPA 1991). If the cumulative risk is less than $10^{-4}$, action generally is not required, but may be warranted if a risk-based chemical-specific standard (for example, maximum contaminant level) is exceeded.

### Future Adult Resident (Noncarcinogenic Hazard)

The risk assessment assumed that a future adult resident could be exposed to soil (0 to 10 feet bgs) through incidental ingestion and dermal contact and to particulate and volatile emissions from soil through inhalation, and groundwater through ingestion and dermal contact. Table 9.1.RME in the attachment summarizes the hazard to the future adult resident.

The RME noncarcinogenic hazard (11) for groundwater exposure pathways is above USEPA's target HI of 1 (Table 9.1.RME in the attachment). The cumulative RME noncarcinogenic hazard (13) for the soil and groundwater exposure pathways is above USEPA's target HI of 1 (Table 4). Dissolved manganese and thallium associated with the groundwater ingestion exposure pathway are the greatest contributors to noncancer hazards. Manganese was the only soil COPC with an HI greater than 1 (Plexus 2006). Carcinogenic risks were not calculated for an adult resident but were calculated for a lifetime resident (that is, a combined 30-year child/adult receptor scenario), following USEPA guidance.

### Future Child Resident (Noncarcinogenic Hazard)

The risk assessment assumed that a future child resident could be exposed to soil (0 to 10 feet bgs) through incidental ingestion and dermal contact and to particulate and volatile emissions from soil through inhalation, and groundwater through ingestion and dermal contact. Table 9.2.RME in the attachment summarizes the hazard to the future child resident.

The RME noncarcinogenic hazard (27) for groundwater exposure pathways is above USEPA's target HI of 1 (Table 9.2.RME in the attachment). Dissolved arsenic, iron, manganese, and thallium associated with the groundwater ingestion and dermal exposure routes are the greatest contributors to noncancer hazards. The cumulative RME noncarcinogenic hazard (40) for the soil and groundwater exposure pathways is above USEPA's target HI of 1 (Table 4). Manganese was the only soil COPC with an HI greater than 1, primarily associated with the soil dermal contact exposure pathway (Plexus 2006).

Carcinogenic risks were not calculated for a child resident but were calculated for a lifetime resident, following USEPA guidance.

### Future Lifetime Resident (Carcinogenic Risk)

The risk assessment assumed that a future lifetime resident could be exposed to soil (0 to 10 feet bgs) through incidental ingestion and dermal contact and to particulate and volatile emissions from soil through inhalation, and groundwater through ingestion and dermal contact. Table 9.3.RME in the attachment summarizes the carcinogenic risk to the future lifetime resident.

The groundwater RME carcinogenic risk ($2\times 10^{-4}$) is above USEPA's risk management range of $1 \times 10^{-6}$ to $1 \times 10^{-4}$ (Table 9.3.RME in the attachment). The groundwater carcinogenic risk is associated with dissolved arsenic, the only carcinogenic groundwater COPC. The cumulative RME carcinogenic risk ($3 \times 10^{-4}$) for the soil and groundwater exposure pathways is above USEPA's risk management range of $1 \times 10^{-6}$ to $1 \times 10^{-4}$ (Table 4). The risk from arsenic associated with soil exposure pathways contributes more than 70 percent of the total soil risks (Plexus 2006).

### Future Industrial Worker

The risk assessment assumed that a future industrial worker could be exposed to surface soil through incidental ingestion and dermal contact and to particulate and volatile emissions from surface soil through inhalation, and groundwater through ingestion. Table 9.4.RME in the attachment summarizes the hazard and risk to the future industrial worker.

The groundwater RME noncarcinogenic hazard (4) is above USEPA's target HI of 1, with dissolved manganese as the greatest contributor. The groundwater RME carcinogenic risk ($1.8 \times 10^{-6}$) is within USEPA's risk management range of $1 \times 10^{-6}$ to $1 \times 10^{-4}$.

The cumulative RME noncarcinogenic hazard (5) for the soil and groundwater exposure pathways for the future industrial worker is above USEPA's target HI of 1 (Table 4). The HI from all COPCs for soil exposure pathways is equal to USEPA's target HI of 1 (Plexus 2006). The dermal contact pathway contributed approximately 95 percent of the total HI. The cumulative soil and groundwater RME carcinogenic risk ($4 \times 10^{-6}$) is within USEPA's risk management range of $1 \times 10^{-6}$ to $1 \times 10^{-4}$.

### Future Construction Worker

The risk assessment assumed that a future construction worker could be exposed to shallow groundwater in an excavation through dermal contact, total soil through incidental ingestion and dermal contact, and particulate and volatile emissions from total soil through inhalation during excavation and construction activities. Table 9.5.RME in the attachment summarizes the hazard and risk to the future construction worker.

The groundwater RME noncarcinogenic hazard (0.5) is below USEPA's target HI of 1. The RME carcinogenic risk ($1.2 \times 10^{-7}$) is below USEPA's risk management range of $1 \times 10^{-6}$ to $1 \times 10^{-4}$.

The cumulative RME noncarcinogenic hazard for the soil and groundwater exposure pathways for the future industrial worker is equal to USEPA's target HI of 1 (Table 4). The HI (0.9) from all COPCs for soil exposure pathways is below USEPA's target HI of 1 (Plexus 2006). The cumulative soil and groundwater RME carcinogenic risk ($5 \times 10^{-7}$) for the construction worker is below USEPA's risk management range of $1 \times 10^{-6}$ to $1 \times 10^{-4}$.

## Uncertainty Assessment

A number of uncertainties are inherent in the estimates of potential cancer risks and noncancer health hazards presented in this updated HHRA. These uncertainties generally are associated with the data evaluation, risk characterization process, or the assumptions and models that make up the risk assessment process. The potential effect of the uncertainties on risk estimates (overestimation or underestimation) varies from readily predicted to difficult to assess. Thus, it is important to specify the assumptions and uncertainties inherent in the risk assessment to place the risk estimates in proper perspective (USEPA 1989).

The key uncertainties associated with the risk calculations for groundwater exposure pathways at the Pioneer AOC include the following:

- Constituents that were not detected in any of the samples in groundwater were not carried through the risk assessment with the exception of metals (total and dissolved). However, one-half the reporting limit for the nondetected constituents was compared to the COPC screening criteria. For groundwater, a number of VOCs and SVOCs were not detected but have reporting limits that exceeded the screening level. The reporting limits generally were an order of magnitude greater than the screening value or maximum contaminant level. Some uncertainty is associated with undetected constituents that have reporting limits above the screening levels; however, based on past site use and concentrations of those constituents detected in groundwater, this is expected to overstate potential risks. A level of bias associated with J-qualified and UJ-qualified data indicates whether the concentration was biased high or low. The data were used in the screening as reported with J or UJ qualifiers, as if the bias was unknown. The use of J-qualified and UJ-qualified data as the reported concentration may result in either under- or overestimation of the actual concentrations based on the level of bias.

- Although there is no current use of groundwater as potable water and future use is not likely, as a conservative measure, future potable use of groundwater at the Pioneer AOC was evaluated as a complete exposure pathway for residential and industrial worker receptor populations. Based on current use and future plans to maintain current land use at Pioneer AOC, it is not likely that groundwater would ever be used as a potable source. Additionally, the exposure factors used for the quantitation of exposure were conservative and reflect worst-case or upper-bound assumptions on the exposure. The reliability of the values chosen for the exposure factors also contributes substantially to the uncertainty of the resulting risk estimates. Because most of the exposure factors are worst-case or upper-bound assumptions, the resulting risks are worst-case estimates. Therefore, the risk estimates for the potable use scenarios reflect worst-case or upper-bound risks that overstate reasonably anticipated exposure scenarios, and do not provide the risk characterization for current or probable future land use.

- The maximum detected concentrations in groundwater of the wells evaluated were used as the EPCs for the groundwater COPCs. This likely overestimates the actual risk as it is unlikely exposure would occur to groundwater from one water table well or that the concentrations in the well would remain constant during the exposure period.

- For dissolved arsenic, manganese, and thallium, the maximum concentration from the most recent site well data (MW-05, MW-06, and MW-08) in July 2009 was used as the EPCs. Dissolved arsenic and thallium were not detected in the July 2009 sampling event, and the reporting limits of each from that event were used as the EPCs. The dissolved arsenic reporting limit (9.9 µg/L) used as the EPC is greater than any of the detected concentrations of dissolved arsenic from October 2008 to July 2009 (2.4-J µg/L to 7.6-J µg/L). Additionally, the ambient well nearest to the Pioneer AOC (see attachment) that is sampled in Ohio EPA's Ambient Groundwater Monitoring Program (Ohio EPA 2008) has detected arsenic concentrations within the range of 10 to 20 µg/L. Therefore, using the dissolved arsenic reporting limit (9.9 µg/L) as the EPC likely results in the overestimation of potential risks and hazards, and those estimates could be attributable to background levels.

  The dissolved thallium July 2009 reporting limit (5.1 µg/L) is within the range and same order of magnitude as the detected dissolved thallium concentrations from October 2008 to July 2009 (2.2-J µg/L to 12-J µg/L). Dissolved thallium was not detected at MW-05, and detections from October 2008 to July 2009 at MW-06 ranged from 2.2-J µg/L to 3.6-J µg/L. Similarly, dissolved thallium concentrations at MW-08 were 2.5-J µg/L and 2.7-J µg/L in January and April 2009, respectively. Although the dissolved thallium EPC used in the risk assessment is below the maximum detected concentration from an earlier round of sampling, the resulting risks would be unchanged because there is not a cancer slope factor available for thallium. Although using dissolved thallium EPC of 5.1 µg/L results in incrementally lower hazards, the results still indicate the same order of magnitude of hazards above USEPA's target HI of 1 for thallium.

- Dissolved arsenic, manganese, and thallium were primary contributors to hazards and risks for the residential and industrial potable use scenarios. However, there is no known source of these constituents related to current or past activities at the Pioneer AOC. Concentrations of dissolved arsenic, manganese, and thallium based on the most recent site well data from July 2009 were compared to quarterly background well data (BG-01 and BG-02) from October 2008 to July 2009 to evaluate the influence of site concentrations versus background concentrations on the hazard and risk results.

  Dissolved arsenic and thallium were not detected in the most recent groundwater sampling event (July 2009) used to evaluate hazards and risks, but were identified as COPCs because one-half the reporting limit for each was above its respective screening level. Hazards and risks for dissolved arsenic and thallium were calculated using the analyte reporting limits. The dissolved arsenic reporting limit (9.9 µg/L) was slightly greater, but within the same order of magnitude as the two detections of dissolved arsenic (3.1-J µg/L and 3.8-J µg/L) at the background well locations, indicating more than one-third of the risk and hazard estimates for dissolved arsenic could be attributable to background levels.

The reporting limit for dissolved thallium (5.1 µg/L) is similar to, but slightly below the maximum of the two detections of dissolved thallium (2.9-J µg/L and 5.4 µg/L) at the background well locations, indicating that risk and hazard estimates for dissolved thallium are reflective of background levels in groundwater and likely overestimate potential risks and hazards from site-related activities.

The range of dissolved manganese concentrations (4.6-J µg/L to 176 µg/L) at two of the three site wells (MW-05 and MW-06) were below or within the range of dissolved manganese concentrations detected in background wells (25.8 µg/L to 236 µg/L). Therefore, potential hazards associated with dissolved manganese at site wells MW-05 and MW-06 could be attributable to background levels. The maximum dissolved manganese concentration from MW-08 in July 2009 (4,640 µg/L) was used as the EPC to calculate potable use noncancer HIs for residential and industrial use scenarios. The RI addendum (CH2M HILL 2011a) noted that reducing conditions found at the Pioneer AOC may be enhancing dissolution of certain metals such as manganese and iron. The dissolved concentrations of these metals may be related to organic rich soils or buried materials that may be present near the respective site wells where elevated concentrations were observed. Therefore, numerical results for dissolved manganese more reasonably reflect conditions in the vicinity of MW-08 and likely overstate noncancer hazards across the Pioneer AOC. The RI addendum (CH2M HILL 2011a) concluded that if groundwater reverts to less reducing conditions as it flows away from the Pioneer AOC area, the dissolved metals would be expected to precipitate and thus be immobilized.

- Potential hazards and risks were calculated using the average groundwater concentration to evaluate CTE when RME results indicated potential risks above USEPA target cancer risk level of $1x10^{-4}$ and noncancer HI of 1 for the adult resident, child resident, lifetime resident, and industrial worker scenarios. The results of the CTE evaluation (Tables 9.1.CTE through 9.4.CTE in the attachment) for the adult resident, child resident, lifetime resident, and industrial worker scenarios indicate groundwater noncarcinogenic hazards are above USEPA's target HI of 1, with the exception of the industrial worker HI of 1. These results primarily are associated with maximum concentrations at MW-05 for groundwater COPCs, with the exception of total and dissolved manganese that are associated with MW-08. The cumulative groundwater CTE carcinogenic risks for the lifetime resident and industrial worker are within USEPA's risk management range of $1 \times 10^{-6}$ to $1 \times 10^{-4}$. The CTE results based on average concentrations in groundwater more likely reflect actual exposures and indicate that RME estimates based on maximum concentrations likely overestimate actual risk.
- A large degree of uncertainty is associated with using oral RfDs and CSFs based on administered doses to dermal RfDs and CSFs based on absorbed doses that are no longer recognized for use by USEPA. The use of these values for barium, cadmium, and iron may result in an underestimation or overestimation of the actual toxicity associated with each COPC; however, none of these COPCs was a significant risk driver in soil or groundwater, and overall conclusions would remain as presented.

# Risk Summary

This HHRA was performed to evaluate potential future risks associated with detected constituents in groundwater at the site. Potential risks associated with exposure to soil COPCs were evaluated in the RI HHRA (Plexus 2006). The risk calculations for the construction worker scenario were corrected in the RI addendum (CH2M HILL 2011a). The soil exposure results from this updated HHRA confirm the results of the RI HHRA (Plexus 2006) and RI addendum (CH2M HILL 2011a) evaluation of the construction worker exposure to soil. Between the three reports, risks at the site were evaluated for exposure to:

- Surface soil for industrial workers
- Surface and subsurface soil for future construction workers and residents
- Potable use of groundwater for future residents and industrial workers
- Shallow groundwater for construction workers during excavation activities

The cumulative risk assessment results of each of these exposure scenarios are summarized in this section.

Table 4 and Tables 9.1.RME through 9.5.RME in the attachment summarize the cancer risks and HIs for exposure to groundwater. Tables 10.1.RME through 10.4.RME in the attachment show only the constituents that contributed HIs above 0.1 to total cumulative receptor HIs greater than 1 or carcinogenic risks greater than $1 \times 10^{-5}$ that contributed to total cumulative receptor carcinogenic risks greater than $1 \times 10^{-5}$ for groundwater exposures. Results of this updated HHRA indicate that potential future residential use would pose noncancer hazards (11 for adult resident and 27 for child resident) and cancer risks ($3 \times 10^{-4}$) for lifetime residents above target levels. The groundwater HHRA also indicates that potential groundwater consumption by industrial workers would pose noncancer hazards (4) above target levels and cancer risks ($4 \times 10^{-6}$) within target levels. Potential noncancer hazards (0.1) and cancer risks ($3 \times 10^{-8}$) are below target levels for the construction worker groundwater exposure pathway.

The cumulative soil and groundwater exposure scenario hazards for the future residential scenario provide an upper bound estimate of risk posed by the site to support risk management decisions. Results of this risk assessment indicate that potential future residential use would pose noncancer hazards and cancer risks above the USEPA risk management range ($1 \times 10^{-6}$ to $1 \times 10^{-4}$). As noted, the residential land use scenario risk evaluation is provided to determine an upper bound estimate on the level of risk posed by the site. Pioneer AOC is not currently or anticipated to be used for future unrestricted (that is, residential) land use. Therefore, results for the other receptor populations represent more reasonably anticipated exposure scenarios associated with the Pioneer AOC.

Based on the results of this updated HHRA, cumulative cancer risk estimates for site workers exposures to surface soil in the maintained area that surrounds the mound area, trespasser exposure to surface soil in the mound area, industrial worker exposure to surface soil in the maintained area and groundwater, and construction worker exposure to soil and groundwater were below or within USEPA target levels for cumulative cancer risks (that is, cancer risk range of $1 \times 10^{-6}$ to $1 \times 10^{-4}$). Based on these results, no further evaluation is necessary for potential site worker, trespasser, or construction worker exposures to evaluated media at Pioneer AOC.

The HHRA noncancer evaluation of cumulative HIs were less than or equal to the noncancer goal of 1 for the site worker exposure to surface soil in the maintained area that surrounds the mound area, trespasser exposure to surface soil in the mound area, and construction worker exposure to soil and groundwater. Results indicate that potential future industrial worker cumulative soil and groundwater exposure would pose noncancer hazards above the goal of 1; however, there is no current or future groundwater use for industrial workers. Therefore, industrial worker exposures require no further evaluation.

# Recommendations

Based on the results of the HHRA at the Pioneer AOC, a Feasibility Study is warranted at this AOC to evaluate alternatives that ensure that the former disposal area remains protective of human health in the future.

# References

CH2M HILL. 2011a. *Pioneer AOC Remedial Investigation Addendum: Former Wilkins Air Station, Shelby, Ohio*. Prepared for US Army Corps of Engineers, Louisville District. April.

CH2M HILL. 2011b. *Shelby Horizons AOC Remedial Investigation*. Prepared for US Army Corps of Engineers, Louisville District. April.

Ohio Environmental Protection Agency (Ohio EPA) Division of Drinking and Ground Waters. 2008. *Arsenic in Ohio's Ambient Ground Water Monitoring Wells*. August.

Ohio Environmental Protection Agency (Ohio EPA) Division of Emergency and Remedial Response. 2005. *Assessing Compounds without Formal Toxicity Values for Use in Human Health Risk Assessment*. August.

Plexus Scientific Corporation. 2000. *Preliminary Assessment, Wilkins AFS, Shelby, Richland County, Ohio.* Prepared for U.S. Army Corps of Engineers, Louisville District. DERP FUDS Property Number G05OH0972, USACE Contract Number DACA27-98-D-0031, Delivery Order 0004. Columbia, MD. September.

Plexus Scientific Corporation. 2001. *Site Inspection, Pioneer and Shelby AOCs, Former Wilkins AFS, Shelby, Richland County, Ohio.* Prepared for U.S. Army Corps of Engineers, Louisville District. DERP FUDS Property Number G05OH0972, USACE Contract Number DACA27-98-D-0031, Delivery Order 0004. Columbia, MD. March.

Plexus Scientific Corporation (Plexus). 2006. *Pioneer Area of Concern Remedial Investigation/Focused Feasibility Study, Former Wilkins AFS, Shelby, Ohio.* Prepared for the US Army Corps of Engineers, Louisville District. DERP FUDS Property Number G050H0972, USACE Contract Number, DACA27-98-D-0031, Delivery Order 0007. Alexandria, VA. June.

Shelby Municipal Utilities. 2009. *Annual Water-Quality Report for 2009*. Division of Water.

U.S. Environmental Protection Agency (USEPA). 1989. *Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual, Part A, Interim Final.* Office of Solid Waste and Emergency Response. EPA/540/1-89/002. December.

U.S. Environmental Protection Agency (USEPA). 1991. *Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual, Part B: "Development of Risk-based Preliminary Remedial Goals*." Office of Solid Waste and Emergency Response. OSWER Directive 9285.7-01B. December 13.

U.S. Environmental Protection Agency (USEPA). 1996. *Soil Screening Guidance: User's Guide*. Office of Solid Waste and Emergency Response, Washington, DC. EPA/540/R-96/018. April.

U.S. Environmental Protection Agency (USEPA). 1997a. *Exposure Factors Handbook*.

U.S. Environmental Protection Agency (USEPA). 1997b. *Health Effects Assessment Summary Tables, FY-1997 Annual* (HEAST). Office of Research and Development. July.

U.S. Environmental Protection Agency (USEPA). 2001. *Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual, Part D*.

U.S. Environmental Protection Agency (USEPA). 2002. *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites.* OSWER 9285.6-10. Office of Emergency and Remedial Response, Washington, DC. December.

U.S. Environmental Protection Agency (USEPA). 2003a. *Human Health Toxicity Values in Superfund Risk Assessments.* OSWER Directive 9285.7-53. December.

U.S. Environmental Protection Agency (USEPA). 2007. *Integrated Exposure Uptake Biokinetic Model for Lead in Children, Windows® version (IEUBK) Windows® 32-bit version*. Office of Solid Waste and Emergency Response, Washington, DC. May.

U.S. Environmental Protection Agency (USEPA). 2003a. *Human Health Toxicity Values in Superfund Risk Assessments*. OSWER Directive 9285.7-53. December.

U.S. Environmental Protection Agency (USEPA). 2003b. *Recommendations of the Technical Review Workgroup for Lead for an Approach to Assessing Risks Associated with Adult Exposure to Lead in Soil*. Office of Solid Waste and Emergency Response. OSWER 9285.7-54. January.

U.S. Environmental Protection Agency (USEPA). 2004a. *Risk Assessment Guidance for Superfund, Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment) Final*. OSWER 9285.7-02EP. July.

U.S. Environmental Protection Agency (USEPA). 2004b. Region 9 Preliminary Remediation Goals (PRG) Table. October.

U.S. Environmental Protection Agency (USEPA). 2009a. *Risk Assessment Guidance for Superfund, Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment) Final*. OSWER 9285.7-82. January.

U.S. Environmental Protection Agency (USEPA). 2009b. Integrated Risk Information System (IRIS) Database.

U.S. Environmental Protection Agency (USEPA). 2009c. *2009 Edition of the Drinking Water Standards and Health Advisories*. Office of Water. EPA 816-F-09-004. May.

U.S. Environmental Protection Agency (USEPA). 2011. Regional Screening Levels for Chemicals at Superfund Sites. June.