

APPENDIX E

Contaminant Fate and Transport Modeling Results

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E. CONTAMINANT FATE AND TRANSPORT

Contaminant fate and transport modeling assesses the potential for SRCs to leach from surface and subsurface soil sources at C Block Quarry and impact groundwater beneath the sources and downgradient receptor locations. Modeling results were included in the decision-making process to determine whether remedial actions may be necessary to protect groundwater resources. Surface water exposure pathways are evaluated in the HHRA and ERA presented in Sections 7.2 and 7.3 of the RI Report, respectively. A summary of the principles of contaminant fate and transport are presented in this section along with the results of the modeling.

Section E.1 describes physical and chemical properties of SRCs found in soil and sediment at the AOC. Section E.2 presents a conceptual model for contaminant fate and transport that considers AOC topography, hydrogeology, contaminant sources, and release mechanisms. Section E.3 presents a soil screening analysis to identify SRCs with the potential to migrate from soil to groundwater as initial CMCOPCs. Section E.4 describes fate and transport modeling using SESOIL to develop the final CMCOPCs and presents the initial CMCOCs based on dilution modeling. Section E.5 provides a list of the remaining CMCOCs and a qualitative assessment of the results and considerations of the limitations and assumptions. Section E.6 presents a summary and conclusions of the fate and transport analysis.

E.1 PHYSICAL AND CHEMICAL PROPERTIES OF SITE-RELATED CONTAMINANTS

The major contaminants of the former RVAAP are TNT, composition B (a combination of TNT and RDX), sulfates, nitrates, lead styphnate, and lead azide. Site-specific contaminants include lead, chromium, and mercury from dumping annealing process waste and spent pickle liquor from brass finishing operations. ACM was also identified in the quarry bottom. This evaluation of contaminant fate and transport evaluates not only those chemicals identified as potential contaminants from previous use but also includes an evaluation of chemicals that were evaluated as part of the overall RI for C Block Quarry. The comprehensive list of surface and subsurface soil SRCs (including 8 inorganic chemicals and 17 organic chemicals) were detailed in Section 4.0 of the RI Report and are summarized below:

- Inorganic SRCs in surface and subsurface soil include arsenic, cadmium, chromium, hexavalent chromium, copper, lead, mercury, and thallium.
- Organic SRCs in surface and subsurface soil include TNT; 2-amino-4,6-DNT; 4-amino-2,6-DNT; anthracene; benz(a)anthracene; benzo(a)pyrene; benzo(b)fluoranthene; benzo(ghi)perylene; benzo(k)fluoranthene; bis(2-ethylhexyl)phthalate; chrysene; fluoranthene; fluorene; indeno(1,2,3-cd)pyrene; nitrocellulose; phenanthrene; and pyrene.

Chemicals released into the environment are susceptible to several degradation pathways, including hydrolysis, oxidation, reduction, isomerization, photolysis, photo-oxidation, biotransformation, and biodegradation. Transformed products resulting from these processes may behave differently than their parent chemical in the environment.

The migration of chemicals is governed by their physical and chemical properties and the surface and subsurface media through which chemicals are transferred. In general, chemicals and structures with similar physical and chemical characteristics will show similar patterns of transformation, transport, or attenuation in the environment. Solubility, vapor pressure data, chemical partitioning coefficients, degradation rates, and Henry's Law Constant (HLC) provide information that can be used to evaluate contaminant mobility in the environment. Partitioning coefficients are used to assess relative affinities of chemicals for solution or solid phase adsorption. However, the synergistic effects of multiple migrating chemicals and complexity of soil/water interactions, including pH and oxidation-reduction potential, grain size, and clay mineral variability, are typically unknown.

The physical properties of the chemicals defined as SRCs in surface and subsurface soil are summarized in Attachment E.1, Tables E.1-1 and E.1-2. These properties are used to assess the anticipated behavior of each chemical under environmental conditions. The physical properties of the chemicals defined as SRCs detected in soil are summarized in Sections E.1.1 through E.1.5.

E.1.1 Chemical Factors Affecting Fate and Transport

The water solubility of a chemical is a measure of the saturated concentration of the chemical in water at a given temperature and pressure. The tendency for a chemical to be transported by groundwater is directly related to its solubility and inversely related to its tendencies to adsorb to soil and volatilize from water (OGE 1988). Chemicals with high water solubilities tend to desorb from soil, are less likely to volatilize from water, and are susceptible to biodegradation. The water solubility of a chemical varies with temperature, pH, and the presence of other dissolved chemicals (including organic carbon and humic acids).

The octanol-water partition coefficient (K_{ow}) can be used to estimate the tendency for a chemical to partition between environmental phases of different polarity. The K_{ow} is a laboratory-determined ratio of the concentration of a chemical in the n-octanol phase of a two-phase system to the concentration in the water phase. Chemicals with $\log K_{ow}$ values less than one are highly hydrophilic, while chemicals with $\log K_{ow}$ values greater than four will partition to soil particles (Lyman et al. 1990).

The water/organic carbon partition coefficient (K_{oc}) is a measure of the tendency of an organic chemical to partition between water and organic carbon in soil. The K_{oc} is defined as the ratio of the absorbed chemical per unit weight of organic carbon to the aqueous solute concentration.

This coefficient can be used to estimate the degree to which an organic chemical will adsorb to soil and thus not migrate with groundwater. The higher the K_{oc} value, the greater is the tendency of the chemical to partition into soil (OGE 1988). The soil/water partitioning coefficient (K_d) is calculated by multiplying the K_{oc} value by the fraction of organic carbon in the soil.

Vapor pressure is a measure of the pressure at which a chemical and its vapor are in equilibrium. The value can be used to determine the extent to which a chemical would travel in air, as well as the rate of volatilization from soil and solution (OGE 1988). In general, chemicals with vapor pressures lower than 10^{-7} mm mercury will not be present in the atmosphere or air spaces in soil in significant

amounts, while chemicals with vapor pressures higher than 10^{-2} mm mercury will exist primarily in the air (Dragun 1988).

The HLC value for a chemical is a measure of the ratio of the chemical's vapor pressure to its aqueous solubility. The HLC value can be used to make general predictions about a chemical's tendency to volatilize from water. Chemicals with HLC values less than 10^{-7} atm-m³/mol will generally volatilize slowly, while chemicals with a HLC greater than 10^{-3} atm-m³/mol will volatilize rapidly (Lyman et al. 1990).

E.1.2 Biodegradation

Organic chemicals with differing chemical structures will biodegrade at different rates. Primary biodegradation consists of any biologically induced structural change in an organic chemical. Complete biodegradation is the biologically mediated degradation of an organic chemical into carbon dioxide, water, oxygen, and other metabolic inorganic products (Dragun 1988). The first order biodegradation rate of an organic chemical is proportional to the concentration:

$$-dC/dt = kC \quad \text{(Equation E-1)}$$

Where:

C = concentration

t = time

k = biodegradation rate constant = $\ln 2/t_{1/2}$

$t_{1/2}$ = biodegradation half-life

The biodegradation half-life is the time necessary for half of the chemical to degrade. The biodegradation rate of an organic chemical generally depends on the presence and population size of soil microorganisms that are capable of degrading the chemical.

E.1.3 Inorganic Chemicals

Inorganic chemicals detected in soil samples are associated with the aqueous phase and leachable metal ions on soil particles. The transport of this material from unsaturated soil to the underlying water table is controlled by the physical processes of precipitation percolation, chemical interaction with the soil, and downward transport of metal ions by continued percolation. The chemistry of inorganic chemical interactions with percolating precipitation and varying soil conditions is complex and includes numerous chemical transformations that may result in altered oxidation states, including ion exchange, adsorption, precipitation, or complexation. The chemical reactions, which are affected by environmental conditions (pH, oxidation/reduction conditions, type and amount of organic matter, clay content, and the presence of hydrous oxides), may act to enhance or reduce the mobility and toxicity of metal ions. In general, these reactions are reversible and add to the variability commonly observed in distributions of inorganic chemicals in soil.

The chemical form of an inorganic chemical determines its solubility and mobility in the environment; however, chemical speciation is complex and difficult to delineate in routine laboratory analysis. Inorganic chemicals in soil are commonly found in several forms, including dissolved concentrations in

soil pore water, metal ions occupying exchange sites on inorganic soil constituents (adsorbed to inorganic soil constituents), metal ions associated with insoluble organic matter, precipitated inorganic chemicals as pure or mixed solids, and metal ions present in the structure of primary or secondary minerals.

The dissolved (aqueous) fraction and its equilibrium sorbed fraction are important when considering the migration potential of inorganic chemicals through soil. Of the inorganic chemicals that are likely to form, chlorides, nitrates, and nitrites are commonly the most soluble. Sulfate, carbonate, and hydroxides generally have low to moderate solubility. Soluble chemicals are transported in aqueous forms subject to attenuation, whereas less soluble chemicals remain as a precipitate and limit the overall dissolution of metal ions. The solubility of the metal ions is also regulated by ambient chemical conditions, including pH and oxidation/reduction.

The attenuation of metal ions in the environment can be estimated numerically using the retardation factor (R), dispersion in higher flow systems (high conductivity environments), and diffusion in low conductivity environments. R defines the extent to which the velocity of the contaminant is slowed, which is largely derived from the K_d . R is calculated using the following equation:

$$R = 1 + (K_d \rho_b) / \theta_w \quad \text{(Equation E-2)}$$

Where:

ρ_b = the soil bulk dry density (g/cm^3)

θ_w = soil moisture content (dimensionless)

Metal ion concentrations in the environment do not attenuate by natural or biological degradation because of low volatility and solubility of the ions. Inorganic chemicals may be biotransformed or bioconcentrated through microbial activity.

E.1.4 Organic Chemicals

Organic chemicals, such as SVOCs or VOCs, may be transformed or degraded in the environment by processes including hydrolysis, oxidation/reduction, photolysis, volatilization, biodegradation, or biotransformation. The half-life of organic chemicals in transport media can vary from minutes to years, depending on environmental conditions and chemical structures. Some types of organic chemicals are very stable, and degradation rates can be very slow. Organic degradation may either enhance (by producing more toxic byproducts) or reduce (reducing concentrations) the toxicity of a chemical in the environment.

E.1.5 Explosives – Related Chemicals

Several explosive compounds were detected in soil at C Block Quarry. Microbiological and photochemical transformation may affect the fate and transport of explosive compounds in the environment. For example, based on the results of culture studies involving the removal of TNT by activated sludge microorganisms, it has been concluded that TNT undergoes biotransformation but not biodegradation (USABRDL 1989). Biotransformation of TNT occurs with the reduction of the

nitro groups by microbial reduction, typically under anaerobic conditions. Beneficial bacteria in these reactions include *Pseudomonas*, *Escherichia*, *Bacillus*, *Citrobacter*, *Enterobacter*, *Klebsella*, *Veillonella*, and *Clostridium* (USACHPPM 2000). It has been found that anaerobic metabolism occurs in two stages (Funk et al. 1993). The first stage is the reductive stage in which TNT is reduced to its amino derivatives. In the second stage, degradation to non-aromatic products begins after the reduction of the third nitro group.

The biotransformation rate of TNT has been found to be rapid at most sites (ERDC 2007) and may be increased with the presence of carbon (USACHPPM 2000). Fungi and photolysis can also biotransform TNT. The predominant transformation products 1,3,5-trinitrobenzene; 4,6-dinitroanthranil; 2,4,6-trinitrobenzaldehyde; and 2,4,6-trinitrobenzylidene are due to photolysis of TNT (USACHPPM 2000). The biotransformation pathway for TNT is shown in Attachment E.1, Figure E.1-1 (Kaplan and Kaplan 1982). The nitro groups of TNT are reduced to form 2-amino-4,6-DNT and 4-amino-2,6-DNT, and the nitro groups can undergo further reduction to form 2,4,6-triaminotoluene (Cockerham and Shane 1994).

Nitrocellulose is an aliphatic nitrate ester that will gelatinize when mixed with nitroglycerin. Nitrocellulose occurs as a fibrous solid that can act as a sorbent that will dissolve in water under highly basic conditions with high temperatures. Nitrocellulose can undergo denitrification as a degradation pathway. Degradation of nitrocellulose to non-reactive nitrocellulose has been observed under methanogenic and fungus-mediated reducing conditions (USACE 2006).

E.2 CONCEPTUAL MODEL FOR FATE AND TRANSPORT

The CSM, which defines the framework for fate and transport modeling, describes conditions at C Block Quarry, including the contaminant sources, surficial and subsurface hydrogeologic conditions, contaminant migration and pathways, and contaminant release mechanisms.

AOC conditions described in Sections 2.0 through 5.0 of the RI Report include contaminant source information, the surrounding geologic and hydrologic conditions, and the magnitude of SRCs and their current spatial distribution. Information from Section 3.0 and the nature and extent evaluation in Section 5.0 were used to develop the CSM for fate and transport modeling by identifying SRCs and migration pathways. The CSM is based on information and data collected for historical investigations, this RI Report, and informed assumptions about the AOC. Assumptions contained in the CSM are reiterated throughout this section. The better the information and the greater the accuracy of the assumptions, the more accurately the CSM describes the AOC; therefore, the more reliable the fate and transport modeling predictions can be. A summary of the salient elements of the CSM that apply to fate and transport modeling are summarized in the following sections.

E.2.1 Contaminant Sources

Primary contaminant sources on the AOC such as ACM are not expected to impact groundwater at the site. Secondary sources (contaminated media) identified in previous investigations are further evaluated in this report.

E.2.2 Hydrogeology

A description of regional and AOC-specific geology and hydrology are summarized below.

- The topography at C Block Quarry ranges from approximately 1,150 ft amsl near the center of the quarry bottom to 1,174 ft amsl at the top of the quarry walls. Surface water drainage associated with heavy rainfall events would follow the topography and drain to the low point in the quarry near the center. There is no perennial standing water in the quarry.
- Soil beneath the AOC consists mostly of silty sands [as observed in subsurface borings installed during the PBA08 RI (Appendix A)]. Soil accumulation at the bottom of the quarry is attributed to historical RVAAP activities, erosion, and/or plant matter decay. Thickness of the soil (observed during the PBA08 RI) at the bottom of the quarry is 0.75–7 ft bgs.
- Five groundwater monitoring wells were installed near the AOC around the edges of the quarry with surface elevations ranging from 1,155.6–1,178.5 ft amsl. The average depth of the monitoring wells is 1,128 ft amsl. This is approximately 46 ft below the topographic high within the AOC (1,172 ft amsl) and approximately 22 ft below the topographic low within the AOC (1,150 ft amsl). These monitoring wells monitor the bedrock zone and are screened in the Homewood Sandstone (TEC-Weston 2018).
- Similar to the general direction of groundwater flow through the Homewood formation, the predominant flow direction at C-Block Quarry is southeast towards Sand Creek (TEC-Weston 2018) (Figure E-3).
- April 2017 water level elevations at the AOC ranged from 1,132.02–1,138.96 ft amsl with the highest elevation at well CBLmw-003, as shown in Figure E-3 (TEC-Weston 2018). Potentiometric data indicate the groundwater table occurs within bedrock throughout the AOC at an average elevation of 1137 ft amsl. The groundwater table is approximately 32 ft below the topographic high within the AOC (1,172 ft amsl) and approximately 13 ft below the topographic low within the AOC (1,150 ft amsl).

E.2.3 Contaminant Release Mechanisms and Migration Pathways

Based on the information presented above, the following contaminant release mechanisms and migration pathways have been identified at the AOC:

- Contaminant leaching from soil to the water table (vertical migration) and lateral transport to downgradient receptors (i.e., Sand Creek and southeast of C Block Quarry).

The principal migration pathway at the AOC is percolation through the unsaturated soil to the water table (i.e., vertical leaching of contaminants from soil into groundwater). However, because of the very heterogeneous nature of the unconsolidated glacial material, groundwater flow patterns within the unconsolidated soil are difficult to predict. Precipitation that does not leave the AOC as surface runoff percolates into the subsurface. Some of the percolating water leaves this environment via evapotranspiration after little or no vertical migration.

The remainder of the water percolates into the water table. As discussed in Section E.2.4, the rate of percolation is controlled by soil cover, ground slope, saturated conductivity of the soil, and meteorological conditions. Figure E-1 illustrates the contaminant migration conceptual model.

Once the contaminant leachate percolates through the soil and reaches the water table, it migrates with the local groundwater and discharges at the downgradient receptors. The groundwater flow direction was based on five wells gauged in 2017, which creates a radial water table surface (Figure E-3) (TEC-Weston 2018). Groundwater flow likely occurs along preferential pathways (e.g., sand seams, channel deposits, or other stratigraphic discontinuities including discrete fractures) having higher permeabilities. For inorganic chemicals, lateral migration through groundwater will be very limited due to their high retardation by the bedrock material (USACE 2003).

Additional factors that affect the leaching rate include a chemical's solubility, sorption capacity (expressed by the K_d), and the amount of percolation. Insoluble chemicals will precipitate out of the solution in the subsurface or remain in insoluble forms with little leaching.

Another factor that affects whether a chemical will reach the water table through percolation of precipitation is the chemical's rate of decay. Most organic compounds decay at characteristic rates proportional to the chemical's half-life. For a given percolation rate, those chemicals with long half-lives have a greater potential for contaminating groundwater than those with shorter half-lives. For this analysis, the rate of decay/half-life was not considered.

Contaminant releases through gaseous emissions and airborne particulates are not significant at C Block Quarry. VOCs were not found and were either never present, or had already volatilized. The AOC is vegetated, located in a humid temperate climate, and soil moisture is typically high, which prevents dust borne contaminant migration. Therefore, there is likely little to no gaseous emission, and contaminant levels in the air pathway are minor to nonexistent.

E.2.4 Water Budget

The potential for contaminant transport begins with precipitation. Percolation is the driving mechanism for leaching of soil contaminants to groundwater. The actual amount of rainwater available for flow and percolation to groundwater is highly variable and depends upon soil type and climatic conditions. A water balance calculation can be used as a tool to quantitatively account for all components of the hydrologic cycle. The quantified elements of the water balance are used for inputs to the soil leaching and groundwater transport models discussed later. The components of a simple steady-state water balance model include precipitation, evapotranspiration, surface runoff, and groundwater recharge or percolation.

These terms are defined as follows:

$$P = ET + Sr + q \quad \text{(Equation E-3)}$$

or

$$\text{Rainwater available for flow} = Sr + q = P - ET \quad \text{(Equation E-4)}$$

Where:

P = precipitation

Sr = surface runoff

ET = evapotranspiration

q = groundwater recharge or percolation

It is expected that loss of runoff also occurs in the form of evaporation. The remaining water, after runoff and evaporation, is available for percolation which includes loss to the atmosphere by evapotranspiration. The water balance estimations were developed using the Hydrologic Evaluation of Landfill Performance (HELP) model (USEPA 1994). See Attachment E.1, Table E.1-3 for parameters used in the HELP model to develop the water budget estimates used in the evaluation. Calculations using precipitation and temperature data for a 100-year period were generated synthetically using coefficients for Cleveland, Ohio (e.g., the nearest weather station to Camp Ravenna with HELP model coefficients).

The annual average water balance estimates indicate an evapotranspiration of 28% (10.3 inches) of total precipitation (37 inches). The remaining 72% (27 inches) of rainwater is available for surface water runoff and percolation to groundwater. Of the 72% (27 inches) of water available for runoff or percolation, groundwater recharge (percolation) accounts for 13% (3.6 inches), and surface runoff (along downgradient topography to nearest surface water bodies) accounts for the remaining 87% (23.4 inches).

E.3 SOIL SCREENING ANALYSIS

Soil screening analyses are screening evaluations performed to identify SRCs with the potential to leach to groundwater as initial CMCOPCs. This section describes the soil screening analysis approach and presents the limitations and assumptions.

E.3.1 Analysis Approach

The five steps for the soil leachability analysis are illustrated in Figure E-2 and are described below.

The first step of the soil screening analysis is developing SRCs, as presented Section 4.0 of the RI Report. A summary of SRCs identified for soil is presented in Section E.1.

The second step of the soil screening process (Figure E-2) involves comparing maximum concentrations of SRCs with MCL-based generic soil screening levels (GSSLs). GSSLs were developed for Superfund sites for contaminant migration to groundwater (USEPA 1996, USEPA 2015). The GSSL is defined as the concentration of a chemical in soil that represents a level of

contamination below which there is no concern for impacts to groundwater under CERCLA, provided conditions associated with USEPA risk-based soil screening level (SSLs) are met. Generally, if chemical concentrations in soil fall below the GSSL, and there are no groundwater receptors of concern or anticipated exposures, then no further study or action is warranted for that chemical. If the GSSL for a chemical is not available, the USEPA risk-based SSL for groundwater migration, dated June 2015 (USEPA 2015), obtained from the USEPA RSL website is used. If neither the GSSL nor the USEPA risk-based SSL for a chemical are available, then no further evaluation of the chemical is performed and it is eliminated from the list of initial CMCOPCs. However, some chemicals have been assigned surrogates by risk assessors if the chemical without an SSL is similar to another chemical with an SSL. Surrogates used for this analysis include pyrene for benzo(ghi)perylene and phenanthrene.

The initial CMCOPC screen, as presented in Attachment E.1, Table E.1-4, eliminates 3 inorganic SRCs, including trivalent chromium and mercury, and 12 organic SRCs from further consideration. There were five inorganic and five organic SRCs carried forward to the third step of the initial soil CMCOPC screening process.

The third step of the soil screening process (Figure E-2) involves comparing the maximum chemical concentrations with the site-specific soil screening level (SSSLs). The SSSL is defined as the GSSL (or the USEPA risk-based SSL for groundwater protection if a GSSL is not available) multiplied by the AOC-specific dilution attenuation factor (DAF). Direct partitioning is used to derive the GSSLs, assuming groundwater is in contact with the chemicals in soil and the groundwater concentration is equal to the leachate concentration. However, as leachate moves through soil, chemical concentrations are attenuated by adsorption and degradation. When the leachate reaches the water table, dilution by groundwater further reduces leachate concentrations. This concentration reduction can be expressed by a DAF. DAFs can vary based on AOC-specific characteristics (e.g., hydrogeologic properties, contaminated source area, and depth to contamination). As described in the *Soil Screening Guidance: Technical Background Document* (USEPA 1996), chemical dilution in groundwater is estimated at each AOC from an AOC-specific DAF. The DAF, which is defined as the ratio of soil leachate concentration to receptor point concentration, is minimally equal to one. Dilution in groundwater is derived from a simple mixing zone equation (Equation E-5) and relies upon estimating the mixing zone depth (Equation E-6).

$$DAF = 1 + \frac{(K \times i \times d)}{(q \times L)} \quad \text{(Equation E-5)}$$

Where:

- DAF = dilution attenuation factor
- K = aquifer hydraulic conductivity (m/yr)
- i = horizontal hydraulic gradient (m/m)
- q = percolation rate (m/yr)
- L = source length parallel to groundwater flow (m)
- d = mixing zone depth (m) (which is defined below)

and

$$d = \sqrt{0.0112 \times L^2 + d_a} \times \left[1 - \exp\left(\frac{-L \times I}{K \times i \times d_a}\right) \right] \quad (\text{Equation E-6})$$

Where:

d_a = aquifer thickness (m)

$d \leq d_a$

As stated above, if the aquifer thickness is less than the calculated mixing zone depth, then the aquifer thickness is used for “d” in the DAF calculation. The DAF calculation for the AOC is presented in Attachment E.1, Table E.1-5. It should be noted that the purpose of this screen is not to identify chemicals that may pose risk at downgradient locations, but to target those chemicals that pose the greatest problem if they migrate from the AOC.

Based on this screening and an AOC-specific DAF of 1.85, benzo(b)fluoranthene was eliminated from further consideration. All the remaining SRCs exceeded their respective SSSLs and were identified as initial CMCOPCs based on leaching to groundwater. The SRCs identified as initial CMCOPCs are presented in Attachment E.1, Table E.1-6. The horizontal hydraulic gradient (0.0028 ft/ft) used in this analysis was based on a groundwater potentiometric surface using water level data collected in 2012. This hydraulic gradient is significantly lower than the gradient (0.005 ft/ft) based on a revised groundwater potentiometric surface using 2017 water level data. The DAF would increase to 2.41 if the hydraulic gradient from 2017 water level data was used, thereby increasing the SSSL values and potentially decreasing the number of initial CMCOPCs.

The fourth step of the soil screening process (Figure E-2) involves eliminating initial CMCOPCs identified in the SSSL evaluation from further consideration that require more than 1,000 years to leach through the unsaturated zone before reaching the water table. A period of 1,000 years was conservatively selected to evaluate eventual migration of the contaminant front to the water table despite uncertainties in vadose zone hydraulic parameters and groundwater recharge over time. Additionally, USACE suggests a screening value of 1,000 years be used due to the high uncertainty associated with predicting conditions beyond that time frame (USACE 2003). Therefore, the initial CMCOPCs at the selected sources were screened against a travel time of greater than 1,000 years. The travel time in this screen is the time required for an initial CMCOPC to migrate vertically from the base of the soil interval detected above the background concentration to the water table. This distance is the leaching zone, as evaluated in Attachment E.1, Table E.1-7, which may vary across the AOC based on the varying depths of soil sample concentrations above the facility-wide background concentrations or SSSLs and the elevation of the water table. The estimated travel time for each initial CMCOPC to reach the water table is determined using the following equations:

$$T = \frac{Lz \times R}{V_p} \quad (\text{Equation E-7})$$

Where:

T = leachate travel time (year)

Lz = thickness of attenuation zone (ft)

R = retardation factor (dimensionless) (Equation 6-2)

V_p = porewater velocity (ft/year)

and

$$V_p = \frac{q}{\theta_w} \quad \text{(Equation E-8)}$$

Where:

q = percolation rate (ft/year)

θ_w = fraction of total porosity that is filled by water

If the travel time for a chemical from a source area exceeded 1,000 years, then the chemical was eliminated from the list of initial CMCOPCs. Six inorganic SRCs, including hexavalent chromium and lead, and organic SRCs were eliminated from further consideration based on their travel times exceeding 1,000 years. Initial CMCOPCs with travel times less than 1,000 years (TNT; 2-amino-4,6-DNT; and 4-amino-2,6-DNT) were retained for further evaluation (Attachment E.1, Table E.1-7) using the Seasonal Soil Compartment (SESOIL) model. The constituents selected for further evaluation with SESOIL modeling are listed in Table E-1.

In the fifth step (Figure E-2), the initial CMCOPCs (presented in Table E-1) were further evaluated using fate and transport models provided in Section E.4.

E.3.2 Limitations and Assumptions of Soil Screening Analysis

It is important to recognize that acceptable soil concentrations for individual chemicals are highly AOC-specific. The GSSLs used in this screening are based on a number of default assumptions chosen to be protective of human health for most AOC conditions (USEPA 1996). These GSSLs are expected to be more conservative than SSSLs based on AOC conditions. The conservative assumptions included in this analysis are: (1) no adsorption in the unsaturated zone or in the aquifer, (2) no biological or chemical degradation in the soil or aquifer, and (3) contamination is uniformly distributed throughout the source. However, the GSSL does not incorporate the contamination already existing within the aquifer.

E.4 FATE AND TRANSPORT MODELING

Contaminant fate and transport modeling represents the fifth step in the fate and transport screening and evaluation process (Figure E-2). SESOIL modeling was performed for chemicals identified as initial CMCOPCs from the soil screening analysis presented in Section E.3 and summarized in Table E-1. SESOIL modeling was performed to predict chemical concentrations in the leachate immediately beneath the selected source areas and just above the water table. If the predicted maximum leachate concentration of an initial CMCOPC was higher than the facility-wide background concentration and the lowest risk-based screening value (Resident Receptor Adult FWCUG, MCL, or RSL), it was identified as a final CMCOPC and was further evaluated qualitatively based on its mobility, potential dispersion and degradation, and its observed concentration in recent groundwater sampling data to identify whether the CMCOPC would be impacting site groundwater.

The Analytical Transient 1-, 2-, 3-Dimensional (AT123D) model, which is generally used to predict future maximum concentrations in groundwater beneath a source and at downgradient receptor locations for RVAAP AOCs in order to identify the initial CMCOCs, will not be applied for C Block Quarry because the model would not adequately predict contaminant migration through this AOC's highly heterogenous hydrogeologic system.

E.4.1 Modeling Approach

Contaminant transport includes the movement of water and dissolved material from the source areas to groundwater. This occurs as rainwater infiltrates the surface and percolates through the area of contamination, its surrounding soil, and into the saturated zone. The downward movement of water, driven by gravitational potential, capillary pressure, and other components of total fluid potential mobilizes the contaminants and carries them through the soil into the mixing zone with the water table. Lateral transport within the shallow bedrock is controlled by the groundwater gradient, fractures, and hydraulic conductivity. Vertical transport through the overburden to the water table is evaluated with the SESOIL model, and the concentration in the groundwater beneath the source due to mixing of leachate with flowing groundwater in the shallow bedrock is estimated by applying DAF to the leachate concentration. The lateral transport to downgradient receptor locations, conceptually illustrated in Figure E-1, is not simulated.

The output of the contaminant fate and transport modeling is presented as the expected maximum concentration of modeled contaminants at the selected receptor locations. For SESOIL, the receptor location is the groundwater table beneath the source area. For this analysis, one ISM Area (CBLss-004M-SO) was considered as the source of contamination based on the results of the soil screening analysis. A separate SESOIL analysis was performed for each initial CMCOPC listed in Table E-1 and is presented in Figure E-3.

The predicted maximum leachate concentration just above the water table, observed in the SESOIL results, was compared against its applicable RVAAP facility-wide background concentration, as well as RVAAP FWCUGs for the Resident Receptor Adult, MCLs, and RSLs. If the predicted maximum leachate concentration of an initial CMCOPC was higher than the facility-wide background concentration and the lowest risk-based screening value (Resident Receptor Adult FWCUG, MCL, or RSL), the initial CMCOPC was identified as a final CMCOPC and was further evaluated using WOE discussion, including a comparison to groundwater monitoring results for the AOC (if available).

If a predicted maximum leachate concentration was lower than the screening criteria, the chemical was no longer considered a CMCOPC.

For chemicals identified as final CMCOPCs, the SESOIL predicted maximum concentrations in the leachate just above the water table were divided by the DAF to estimate the concentrations in groundwater directly below the source areas and the estimated concentrations were compared to the applicable RVAAP facility-wide background concentrations, as well as RVAAP FWCUGs for the Resident Receptor Adult, MCLs, and RSLs. If the predicted maximum concentration of a final CMCOPC was higher than its facility-wide background concentration and the lowest risk-based

screening value (i.e., Resident Receptor Adult FWCUG, MCL, or RSL), the chemical was retained as an initial CMCOG for WOE evaluation.

The initial CMCOGs identified by modeling results were evaluated with respect to WOE for retaining or eliminating CMCOGs from further consideration as a basis for potential soil remedial actions. Lines of evidence include validating modeling results using available AOC-specific groundwater monitoring data. Modeled timelines for potential leaching were evaluated with respect to estimated times for contaminant releases during RVAAP operations to determine if peak leaching concentrations would likely have occurred in the past. Some initial CMCOGs present at or below RVAAP soil background concentrations may have predicted leachate or groundwater concentrations exceeding risk-based criteria due to conservative model assumptions; therefore, these were also identified and considered in the evaluation. Additionally, identified initial CMCOGs were compared to COCs identified in the HHRA to determine if they had an associated risk related to direct exposure to soil or if initial CMCOGs and COCs were co-located and may be addressed simultaneously under a potential remedial action.

E.4.2 Model Applications

The SESOIL model (GSC 1998) used for leachate modeling, when applicable, estimates pollutant concentrations in the soil profile following introduction via direct application and/or interaction with transport media. The application of the model is discussed in the following subsections.

E.4.2.1 SESOIL Modeling

The SESOIL model defines the soil column as compartments extending from the ground surface through the unsaturated zone and to the upper level of the saturated soil zone or top of bedrock. Processes simulated in SESOIL are categorized in three cycles: hydrologic, sedimentation, and pollutant. Each cycle is a separate submodule in the SESOIL code. The hydrologic cycle includes rainfall, surface runoff, percolation, soil-water content, evapotranspiration, and groundwater recharge. The sediment washload cycle includes erosion and sediment transport. The pollutant cycle includes convective transport, volatilization, adsorption/desorption, and degradation/decay. A chemical in SESOIL can partition in up to four phases (liquid, adsorbed, air, and pure). Data requirements for SESOIL are not extensive and utilize a minimum of AOC-specific soil and chemical parameters and monthly or seasonal meteorological values as input.

The SESOIL model output includes pollutant concentrations at various soil depths and pollutant loss from the unsaturated soil zone in terms of surface runoff, percolation to groundwater, volatilization, and degradation. The mathematical representations in SESOIL generally consider the rate at which the modeled processes occur, the interaction of different processes with each other, and the initial conditions of the waste area and surrounding subsurface matrix material.

The input data for SESOIL can be grouped into four types: climatic, chemical, soil, and application. There are 61 separate parameters contained in these four data groups. Wherever possible, AOC-specific parameter values were used for modeling. However, certain parameters were not available for

the source areas and were estimated based on pertinent scientific literature, geochemical investigations, and checks for consistency between model results and historical data. Conservative estimates were used when a range of values existed or parameter values were not available.

E.4.2.2 Climate Data

The climatic data file of SESOIL consists of an array of mean monthly temperature, mean monthly cloud cover fraction, average monthly relative humidity, average monthly reflectivity of the earth's surface (i.e., shortwave albedo), average daily evapotranspiration, monthly precipitation, mean number of storm events per month, mean duration of rainfall, and mean length of rainy season. The climatic data are presented in Attachment E.1, Table E.1-8. The data set was taken from the Youngstown National Weather Service Office weather station at the Youngstown-Warren Regional Airport in Vienna, Ohio, as it was determined to be most appropriate in corresponding to the latitude and longitude at Camp Ravenna.

Climate data from the Youngstown weather station did not have all of the necessary climatic parameters for the HELP model simulation. Accordingly, the water balance evaluation presented in Section E.2.4 was based on the nearest available weather station data with all necessary coefficients stored within the HELP model (Cleveland, Ohio). Inputs for the SESOIL model (Youngstown station) and HELP model (Cleveland station) produced virtually the same recharge rate (9.40 cm/yr for Cleveland and 9.42 cm/yr for Youngstown) for each location. Therefore, using the two different weather station data sets did not impact modeling results.

E.4.2.3 Chemical Data

The pollutant fate cycle of SESOIL focuses on various chemical transport and transformation processes that may occur in the soil zone. These processes include volatilization/diffusion, adsorption/desorption, cation exchange, biodegradation and hydrolysis, and metal complexation. The chemical-specific parameters used for SESOIL are presented in Attachment E.1, Table E.1-9. The distribution coefficients (K_{ds}) for inorganic chemicals and the K_{oc} values for organic chemicals were obtained from the chemical-specific parameter table associated with the USEPA risk-based generic screening tables (USEPA 2015). The K_{ds} for organic chemicals were estimated from organic, carbon-based K_{oc} using the relationship $K_d = (f_{oc})(K_{oc})$, where f_{oc} = mass fraction of the organic carbon soil content obtained from AOC-specific measurements. In general, biodegradation rates are not applicable for inorganic CMCOPCs and biodegradation was not considered for the organic chemicals in this evaluation.

E.4.2.4 Soil Data

The soil data file of SESOIL contains input parameters describing the physical characteristics of the subsurface soil and is presented in Table E-2. These parameters include soil bulk density, intrinsic permeability, soil disconnectedness index, soil porosity, organic carbon content, and cation exchange capacity. AOC-specific data were used from geotechnical samples collected at the AOC during the PBA08 RI. There is, however, no measurement method for the soil disconnectedness index or a

measured value of the Freundlich exponent. Soil disconnectedness index is a parameter that relates the soil permeability to the moisture content. Thus, SESOIL default values were used for these two parameters.

An average intrinsic permeability for the vadose zone, representing the unconsolidated zone above the water table, was calibrated using the percolation rate of 9.42 cm/yr (3.6 inches/year) as the calibration target. The model was calibrated against the percolation rate by varying the intrinsic permeability and keeping all other AOC-specific geotechnical parameters fixed. The final hydrogeologic parameter values used in this modeling are shown in Table E-2. The soil porosity was set to the AOC-specific value. The intrinsic permeability, calibrated in SESOIL to the percolation rate (determined from a water balance estimated in HELP), was found to match the AOC-specific measurements from geotechnical samples.

The soil disconnectedness index replaces the moisture retention curves (or characteristic curves) used by other unsaturated zone leaching models. SESOIL's User Guide defines this parameter to be the exponent relating the "wetting" and "drying" time-dependent permeability of soil to its saturated permeability (Hetrick and Scott 1993). This "one variable" approach of using the soil disconnectedness index in SESOIL simplifies the data estimation process and reduces computational time. In addition, this parameter was calibrated for four different soil types ranging from sandy loam to clay (Hetrick et al. 1986), and calibrated values fell within the default range specified in the SESOIL's User Guide.

E.4.2.5 Source Terms

Analytical data from surface and subsurface soil collected at the AOC were used as source terms for SESOIL modeling. All the samples collected at different depth intervals were compiled to provide a detailed loading option for the SESOIL model. The maximum soil concentrations for each initial CMCOPC, listed in Table E-1, were used as source term concentrations for the SESOIL model.

E.4.2.6 Application Data

One layering scheme was developed for the source area based on soil sample data and depths to groundwater. Details of the model layers utilized in this modeling are presented in Attachment E.1, Table E.1-10.

The model was arranged in four layers. The top layer (Layer 1) was 1.5 ft thick and divided into three sublayers that were each 0.5 ft thick. The top sublayer (the top 0.5 ft) was the contaminant loading zone, and the remaining two sublayers of Layer 1 served as the leaching zone (as did Layers 2 and 3, which were each 11.5 ft thick). Layer 4, which was 0.5 ft thick was included just above the water table to read output results at the water table/vadose zone interface (i.e., leachate concentration entering groundwater). The depth to groundwater (~25 ft) used in this analysis was based on the groundwater potentiometric surface from 2012 groundwater elevations. This depth to groundwater is still applicable using the 2017 groundwater potentiometric surface that occurs approximately 32 ft below

the topographic high within the AOC (1,172 ft amsl) and approximately 13 ft below the topographic low within the AOC (1,150 ft amsl).

E.4.3 SESOIL Modeling Results

SESOIL modeling was performed for initial CMCOPCs (i.e., TNT; 2-amino-4,6-DNT; and 4-amino-2,6-DNT) that have the potential to reach the water table within 1,000 years based on the soil screening analysis results (Table E-1). Table E-3 presents the predicted peak leachate concentrations beneath the source area corresponding to the time of peak leachate concentrations. The Resident Receptor Adult FWCUGs, RVAAP facility-wide background concentrations, and MCL/RSL values for the initial CMCOPCs, if available, are also shown in this table for comparison purposes. The predicted leachate concentrations below the source and just above the water table for all initial CMCOPCs were above their respective screening criteria; therefore, they were selected as final CMCOPCs. Attachment E.1, Figures E.1-2 through E.1-4 show the leachate concentrations versus time plots predicted by SESOIL that were divided by the DAF to estimate the concentrations in groundwater beneath the source versus time.

TNT; 2-amino-4,6-DNT; and 4-amino-2,6-DNT were identified as final soil CMCOPCs based on SESOIL modeling results for the sample location within the AOC where the leachate concentration exceeded its screening criteria. This leachate concentration does not reflect the groundwater concentration beneath the source. When the leachate reaches the water table, dilution by groundwater further reduces leachate concentrations. Figures E.1-5 through E.1-7 in Attachment E.1 show the estimated groundwater concentrations versus time curves based on dilution of leachate concentrations.

E.4.4 Limitations/Assumptions

In general, a conservative modeling approach was used, which may overestimate the contaminant concentration in the leachate for migration from observed soil concentrations. Listed below are important assumptions used in this analysis:

- The contaminant fate and transport evaluation included not only chemicals identified as being previously used during historical operations, but also included all chemicals identified as soil SRCs during the data screening and reduction process.
- Some soil SRCs were identified due to the absence of a background concentration or as having limited or slight exceedances of the established background concentrations.
- Chemical and biological degradation rates for organic CMCOPCs were not considered in the SESOIL model.
- Using K_d and R to describe the reaction term of the transport equation assumes that an equilibrium relationship exists between the solid-phase and solution-phase concentrations and that the relationship is linear and reversible.
- Since AOC-specific data are not available, the K_d and K_{oc} values used in this analysis for all CMCOPCs represent literature or calculated values and may not represent conditions at the AOC.

- The K_d for inorganic chemicals used in the modeling evaluation assumed a pH of 6.8 [i.e., the middle value in USEPA's evaluation presented in the soil screening guidance document (USEPA 1996)]. The K_d for inorganic chemicals varies with pH (generally decreasing with decreasing pH, although there are few exceptions); therefore, if AOC-specific pH measurements are greater or less than 6.8, the K_d and calculated screening parameters (such as R) will deviate from those presented here.
- Flow and transport in the vadose zone is one-dimensional (i.e., only in the vertical direction). This modeling used the current soil concentrations that were collected approximately 65 years after historical operations were terminated at the AOC. Therefore, it does not account for constituents that have already leached to groundwater.
- Flow and transport are not affected by density variations. Variability in the distribution of soil contamination and overall impacts to predicted groundwater concentrations were not considered in the models. A realistic distribution of soil contamination was not considered. The maximum concentration value was used as the source term concentrations for SESOIL model layers; this is a highly conservative assumption that is expected to produce higher leachate concentrations for CMCOPCs than the average condition. The horizontal distribution of soil contamination was assumed based on concentration levels from nearby sample locations as opposed to taking into account the entire area.
- The water balance represents an overall average rainwater recharge and assumes an even distribution of infiltration in the modeled area. An average water balance assumes some areas will have higher or lower recharge based on the heterogeneity of the soil and varying topography.
- The horizontal gradient and depth to groundwater used in this analysis were based on the potentiometric surface generated from 2012 water level data. Using these parameters results in a more conservative or equivalent assessment compared to using water level data from 2017.

The inherent uncertainties associated with using these assumptions must be recognized. K_d values are highly sensitive to changes in the major chemistry of the solution phase. Therefore, it is important that the values be measured or estimated under conditions that will closely represent those of the contaminant plume. Deviations of actual AOC-specific parameter values from assumed literature values may significantly affect contaminant fate predictions. It is also important to note that the contaminant plume will change over time and will be affected by multiple solutes present at the AOC. The effects of heterogeneity, anisotropy, and spatial distribution of fractures are not addressed in these simulations. The present modeling study using SESOIL does not address the effects of flow and contaminant transport across interfaces in rapidly varying heterogeneous media.

E.5 EVALUATION TO IDENTIFY CMCOCs

This evaluation of contaminant fate and transport uses a soil screening analysis to identify SRCs that have potential to leach to groundwater, performs SESOIL modeling to conservatively estimate final CMCOPC leachate concentrations before the SRCs enter the groundwater system beneath the sources with highest level of contamination, and uses a simple dilution factor to present a conservative maximum concentration in groundwater of final CMCOPCs beneath the sources.

The limitations and assumptions of the overall process are presented in Section E.4.6. The text below provides a list of the remaining CMCOCs after applying a dilution factor to SESOIL modeling results. This qualitative assessment of the results and considerations of the limitations and assumptions will determine if C Block Quarry has CMCOCs.

TNT – The maximum surface soil concentration for TNT (22 mg/kg) was below the Resident Receptor Adult FWCUG at a TR of 1E-06, but slightly above at HQ of 0.1 (i.e., 21.1 mg/kg), and TNT was not considered a COC in the HHRA. TNT modeling results indicate concentrations in groundwater beneath the source area could potentially exceed its RSL and the Resident Receptor Adult FWCUG within 12 years. Based on the AOC period of operations, TNT should have already been detected in the existing groundwater. However, TNT was not detected in groundwater samples collected at the AOC; therefore, this evaluation concludes that the model-predicted concentrations are conservative, and TNT would be expected to be below its SL based on its estimated site-specific biodegradation rate.

2-Amino-4,6-DNT – The maximum surface soil concentration for 2-amino-4,6-DNT (0.54 mg/kg) was below the Resident Receptor Adult FWCUG at a HQ of 0.1, TR of 1E-06 (12.8 mg/kg), and 2-amino-4,6-DNT was not considered a COC in the HHRA. 2-Amino-4,6-DNT modeling results indicate concentrations in groundwater beneath the source area could potentially exceed its RSL and the Resident Receptor Adult FWCUG within 10 years. Based on the AOC period of operations, 2-amino-4,6-DNT should have already been detected in the existing groundwater. However, 2-amino-4,6-DNT was not detected in groundwater samples collected at the AOC; therefore, this evaluation concludes that the model-predicted concentrations are conservative, and 2-amino-4,6-DNT would be expected to be below its SL based on its estimated site-specific biodegradation rate.

4-Amino-2,6-DNT – The maximum surface soil concentration for 4-amino-2,6-DNT (0.64 mg/kg) was below the Resident Receptor Adult FWCUG at a HQ of 0.1, TR of 1E-06 (12.8 mg/kg), and 4-amino-2,6-DNT was not considered a COC in the HHRA. 4-Amino-2,6-DNT modeling results indicate concentrations in groundwater beneath the source area could potentially exceed its RSL and the Resident Receptor Adult FWCUG within 10 years. Based on the AOC period of operations, 4-amino-2,6-DNT should have already been detected in the existing groundwater. However, 4-amino-2,6-DNT was not detected in groundwater samples collected at the AOC; therefore, this evaluation concludes that the model-predicted concentrations are conservative, and 4-amino-2,6-DNT would be expected to be below its SL based on its estimated site-specific biodegradation rate.

This qualitative assessment concludes that the soil contaminants identified as initial CMCOCs for evaluation, due to predicted groundwater concentrations beneath a source, are not adversely impacting groundwater quality based on current data and are not predicted to have future impacts. Potential additional investigation under the Facility-wide Groundwater AOC may be warranted, but based on the fate and transport evaluation, CMCOCs are not identified for C Block Quarry, and no further action is required of soil to be protective of groundwater.

E.6 SUMMARY AND CONCLUSIONS

Inorganic and organic SRCs exist in surface and subsurface soil at C Block Quarry. These SRCs include chemicals that were identified as potential contaminants from previous site usage and chemicals that were identified from the SRC screening process using available data. All SRCs were further evaluated to determine if residual concentrations in soil may potentially impact groundwater quality and warrant evaluation in an FS.

All SRCs identified in surface and subsurface soil at C Block Quarry were evaluated through the stepwise fate and transport evaluation. Among the potential contaminants from previous use, chromium and mercury were eliminated from potentially impacting groundwater through soil screening analysis (i.e., by comparing their maximum soil concentrations to the MCL-based GSSLs); and lead and hexavalent chromium were eliminated since their travel times to reach the water table from the source area exceeded 1,000 years.

Evaluation of modeling results identified TNT; 2-amino-4,6-DNT; and 4-amino-2,6-DNT as initial CMCOs. These initial CMCOs were predicted to exceed the screening criteria in groundwater beneath the source area; however, none of these were detected in historical AOC groundwater samples collected.

A qualitative assessment of the sample results was performed and the limitations and assumptions of the models were considered to identify if any CMCOs are present in soil at C Block Quarry that may potentially impact groundwater at C Block Quarry. Modeling results indicated that the predicted concentrations in groundwater beneath the source area could potentially exceed the RSLs and the Resident Receptor Adult FWCUGs within 10 to 15 years. Based on the AOC period of operations, these constituents should have already been detected in groundwater. However, none of these constituents are detected in groundwater, likely due to biodegradation, which is not accounted in the conservative modeling. This qualitative assessment concluded that CMCOs are not adversely impacting groundwater quality based on current data and are not predicted to have future impacts. No further action is required for soil to be protective of groundwater.

Table E-1. Initial CMCOPCs Evaluated with SESOIL Modeling

Initial CMCOPCs	Maximum Concentrations (mg/kg)	ISM Area	Sample Depth (ft bgs)	Leachate Modeling Required? (Yes/No)
<i>Organic Chemicals – Explosives</i>				
2,4,6-Trinitrotoluene	2.20E+01	CBLss-004M-SO	0-0.5	Yes
2-Amino-4,6-dinitrotoluene	5.40E-01	CBLss-004M-SO	0-0.5	Yes
4-Amino-2,6-dinitrotoluene	6.40E-01	CBLss-004M-SO	0-0.5	Yes

bgs = Below ground surface.

CMCOPC = Contaminant migration chemical of potential concern.

ft = Feet.

ISM = Incremental sampling methodology.

mg/kg = Milligrams per kilogram.

Table E-2. Unit-Specific Parameters Used in SESOIL and Dilution Modeling

Parameters	Symbol	Units	Value	Source for Value
<i>SESOIL</i>				
Percolation Rate (Recharge Rate)	q	m/yr	9.42E-02	0.1 SESOIL Precipitation for Youngstown, Ohio
Horizontal Area of Aggregate	A _p	cm ²	4.04E+06	Based on CBLss-004M ISM area at C Block Quarry
Intrinsic Permeability - clayey sand	p	cm ²	1.05E-10	Calibrated from SESOIL model
Disconnectedness Index	c	unitless	11	Calibrated from SESOIL model
Freundlich Equation Exponent	n	unitless	1	SESOIL default
Fraction Organic Carbon	f _{oc}	unitless	6.70E-04	Average from the PBA08 RI Geotechnical Sample CBLSB-010-5269-SO
Bulk Density	ρ _b	kg/L	1.74	
Moisture Content	w	wt %	13.6	
Water-filled Soil Porosity	T _w	unitless	0.237	
Air-filled Soil Porosity	T _a	unitless	0.114	
Porosity – total	n _T	unitless	0.351	
Vadose Zone Thickness	V _Z	m	7.62	Average based on ground surface elevations and depth to water table from potentiometric surface from 2012 water level data.
Leaching Zone Thickness	T _h	m	7.47	Average based on ground surface elevations and depth to water table from potentiometric surface from 2012 water level data.
Aquifer Thickness	h	m	6	Conservative assumption for shallow bedrock aquifer. Facility-wide assumption for the unconsolidated aquifer presented the Load Line 1 investigation was 6 meters (USACE 2003)
Hydraulic Conductivity in Saturated Zone	K _s	cm/s	3.80E-04	Average of slug test results (MKM 2007)
Hydraulic Gradient	i	unitless	2.82E-03	Average gradient determined from potentiometric surface from 2012 water level data.

Table E-2. Unit-Specific Parameters Used in SESOIL and Dilution Modeling (continued)

Parameters	Symbol	Units	Value	Source for Value
Effective porosity	n_e	unitless	0.2	Assumed for sandstone (USEPA 1985)

MKM 2007. Characterization of 14 AOCs at Ravenna Army Ammunition Plant (March 2007).

USACE (U.S. Army Corps of Engineers) 2003b. Phase II Remedial Investigation Report for the Load Line 1 at the Ravenna Army Ammunition Plant, Ravenna, Ohio. June 2003.

USEPA (U.S. Environmental Protection Agency) 1985. Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Ground Water,

Revised 1985 Parts 1 and 2, EPA/600/6-85/002. Office of Research and Development, Environmental Research Laboratory, Athens, Georgia. September 1985.

cm² = Square centimeters.

cm/s = Centimeters per second.

kg/L = Kilograms per liter.

m = Meter.

m/yr = Meters per year.

PBA08 RI = Performance-based Acquisition 2008 Remedial Investigation.

SESOIL = Seasonal Soil Compartment Model.

wt % = Weight by percent.

Table E-3. Summary of SESOIL Modeling Results

Initial CMCOPC	Maximum Soil Concentration (mg/kg)	ISM Area	Maximum Depth of Contamination (ft bgs)	Depth to Groundwater (ft bgs)	Predicted $C_{\text{leachate, max}}$ Beneath Source (mg/L)	Time Required to Reach $C_{\text{leachate, max}}$ (years)	MCL/RSL (mg/L)	Resident Receptor Adult FWCUG ^a (mg/L)	Facility-wide Background Bedrock Groundwater (mg/L)	Final CMCOPC? ^b (yes/no)
2,4,6-Trinitrotoluene	2.20E+01	CBLss-004M	0.5	25	1.16E+01	11	2.50E-03	1.83E-03	None	Yes
2-Amino-4,6-Dinitrotoluene	5.40E-01	CBLss-004M	0.5	25	3.28E-01	10	3.90E-02	7.30E-04	None	Yes
4-Amino-2,6-Dinitrotoluene	6.40E-01	CBLss-004M	0.5	25	3.87E-01	10	3.90E-02	7.30E-04	None	Yes

^aThe Resident Receptor Adult FWCUG is based on a target risk of 10^{-6} and a hazard quotient of 0.1.

^bThe Final CMCOPC was identified comparing predicted maximum leachate concentration to MCL/RSL, Resident Receptor Adult FWCUGs, and facility-wide background concentrations.

A constituent is a final CMCOPC if its predicted leachate concentration is higher than its facility-wide background concentration and the lowest risk-based screening value (Resident Receptor Adult FWCUG, MCL, or RSL) within 1,000 years.

bgs = Below ground surface.

CMCOPC = Contaminant migration chemical of potential concern.

ft = Feet.

FWCUG = Facility-wide cleanup goal.

ISM = Incremental sampling methodology.

MCL = Maximum contaminant level.

mg/kg = Milligram per kilogram.

mg/L = Milligram per liter.

RSL = Regional screening level.

SESOIL = Seasonal soil compartment model.

Bold = CMCOPCs exceeding MCL/RSL, Resident Receptor Adult FWCUGs, and facility-wide background concentrations.

Table E-4. Summary of Groundwater Modeling Results

Final CMCOPC	Maximum Leachate Concentration^a (C_{leachate, max}) (mg/L)	Predicted Maximum Groundwater Concentration^b Beneath Source (mg/L)	Observed Maximum Groundwater Concentrations^c (mg/L)	MCL/RSL (mg/L)	Resident Receptor Adult FWCUG^d (mg/L)	Facility-wide Background Bedrock Groundwater (mg/L)	CMCOC for Further WOE Evaluation?^e (yes/no)
2,4,6-Trinitrotoluene	1.16E+01	6.25E+00	ND	2.50E-03	1.83E-03	None	Yes
2-Amino-4,6-Dinitrotoluene	3.28E-01	1.77E-01	ND	3.90E-02	7.30E-04	None	Yes
4-Amino-2,6-Dinitrotoluene	3.87E-01	2.09E-01	ND	3.90E-02	7.30E-04	None	Yes

^a Represents SESOIL predicted maximum leachate concentration just above the water table.

^b The predicted concentration was estimated using the results from SESOIL and applying DAF.

^c Observed groundwater concentrations were reported in the *RVAAP Facility-wide Groundwater Monitoring Program 2009 Annual Report* (EQM 2010) and sampling events through 2015 (EQM 2015).

^d The Resident Receptor Adult FWCUG is based on a target risk of 1E-06 and a hazard quotient of 0.1.

^e The CMCOC retained for further WOE evaluation was identified by comparing the predicted concentration in groundwater to MCL/RSL, Resident Receptor Adult FWCUGs, and facility-wide background concentrations. A constituent is a CMCOC retained for WOE evaluation if its predicted concentration in groundwater was higher than its facility-wide background concentration, and the lowest risk-based screening value (Resident Receptor Adult FWCUG, MCL, or RSL) within 1,000 years.

CMCOC = Contaminant migration chemical of concern.

CMCOPC = Contaminant migration chemical of potential concern.

ft = Feet.

FWCUG = Facility-wide cleanup goal.

MCL = Maximum contaminant level.

mg/L = Milligrams per liter.

ND = Not detected.

RSL = Regional screening level.

SESOIL = Seasonal Soil Compartment Model.

WOE = Weight-of-Evidence

Bold = CMCOPCs exceeding MCL/RSL, FWCUGs, and facility-wide background concentrations.

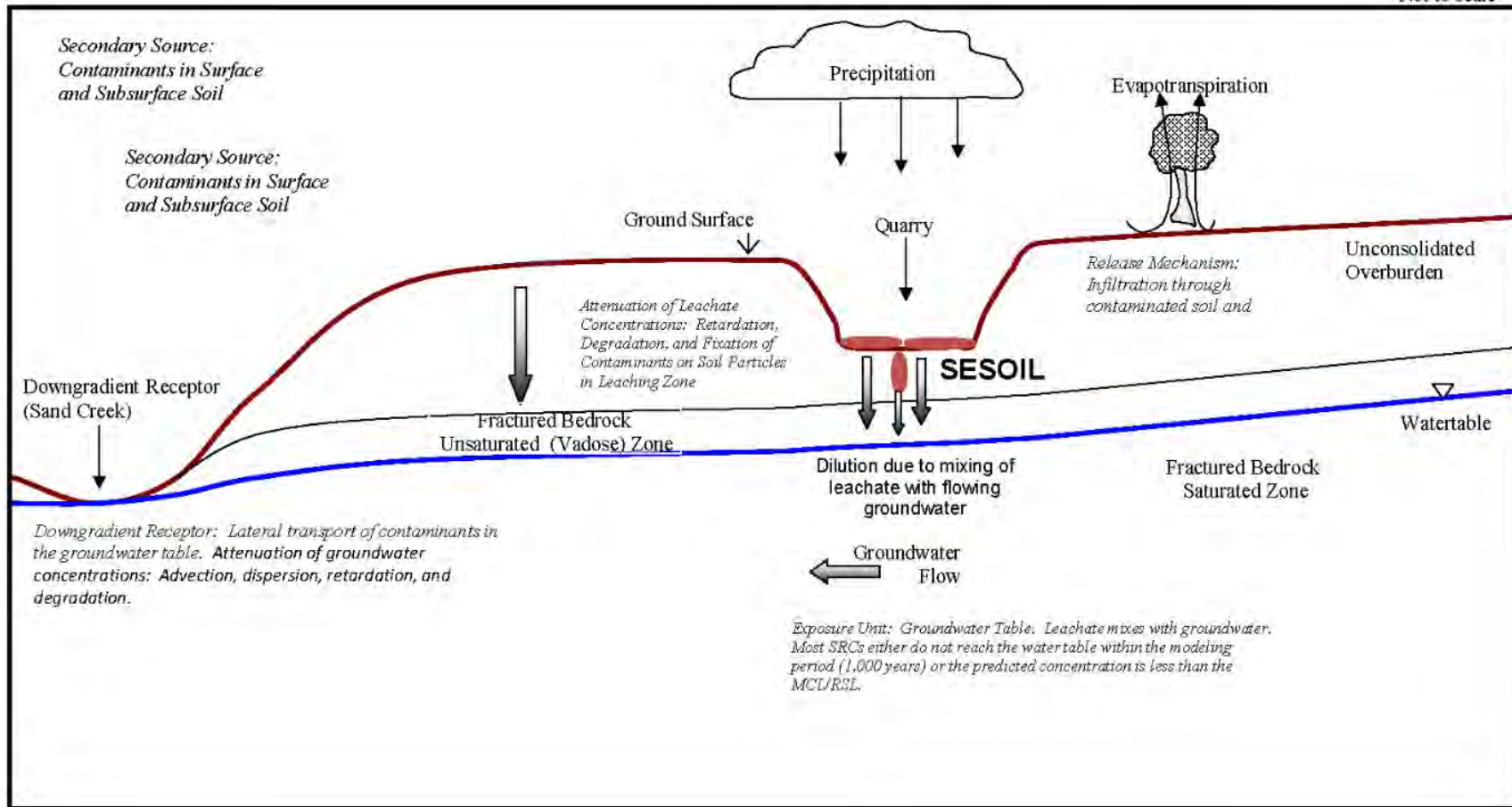


Figure E-1. Contaminant Migration Conceptual Model

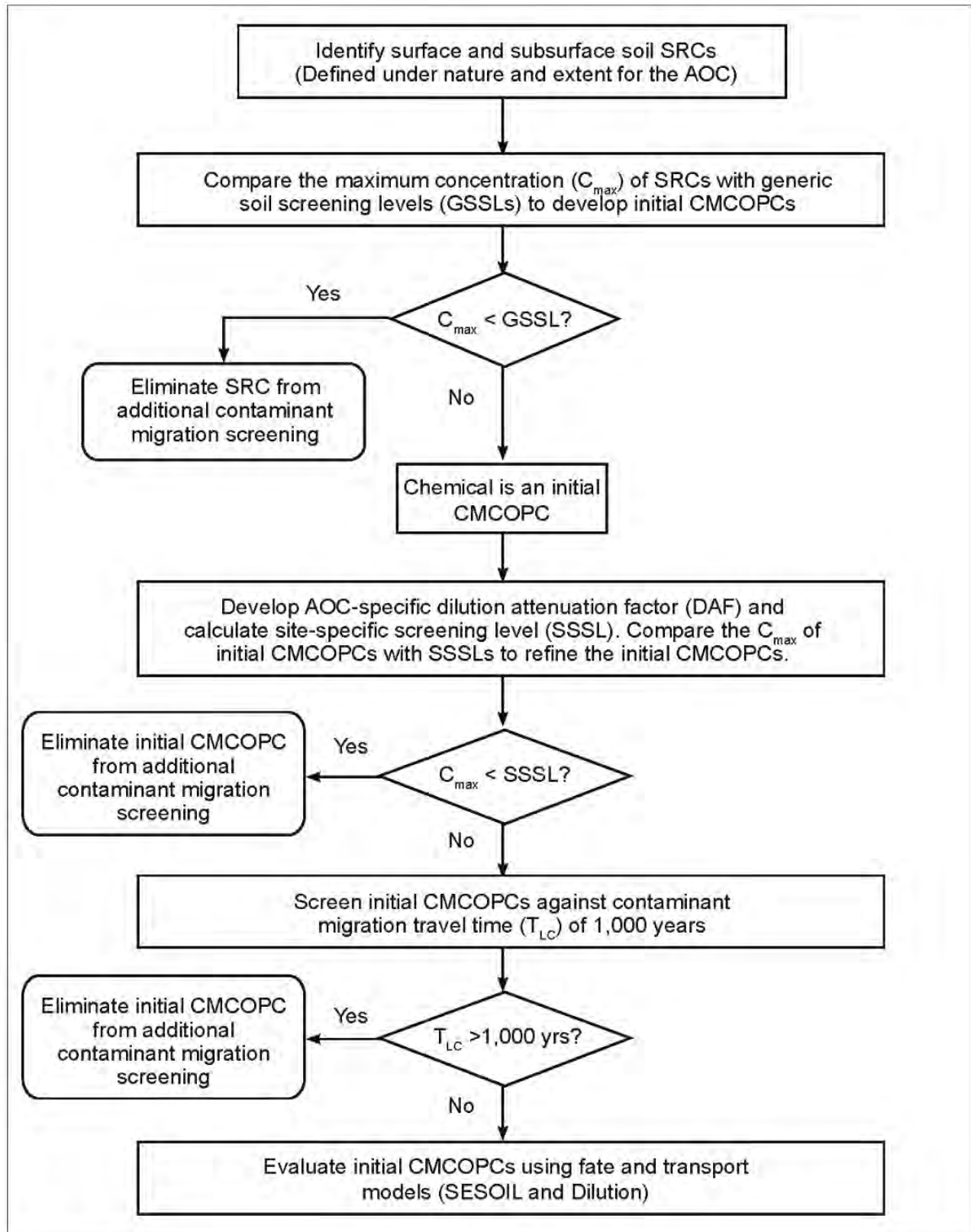


Figure E-2. Initial CMCOPCs Identified in Soil Screening Analysis for SESOIL Evaluation

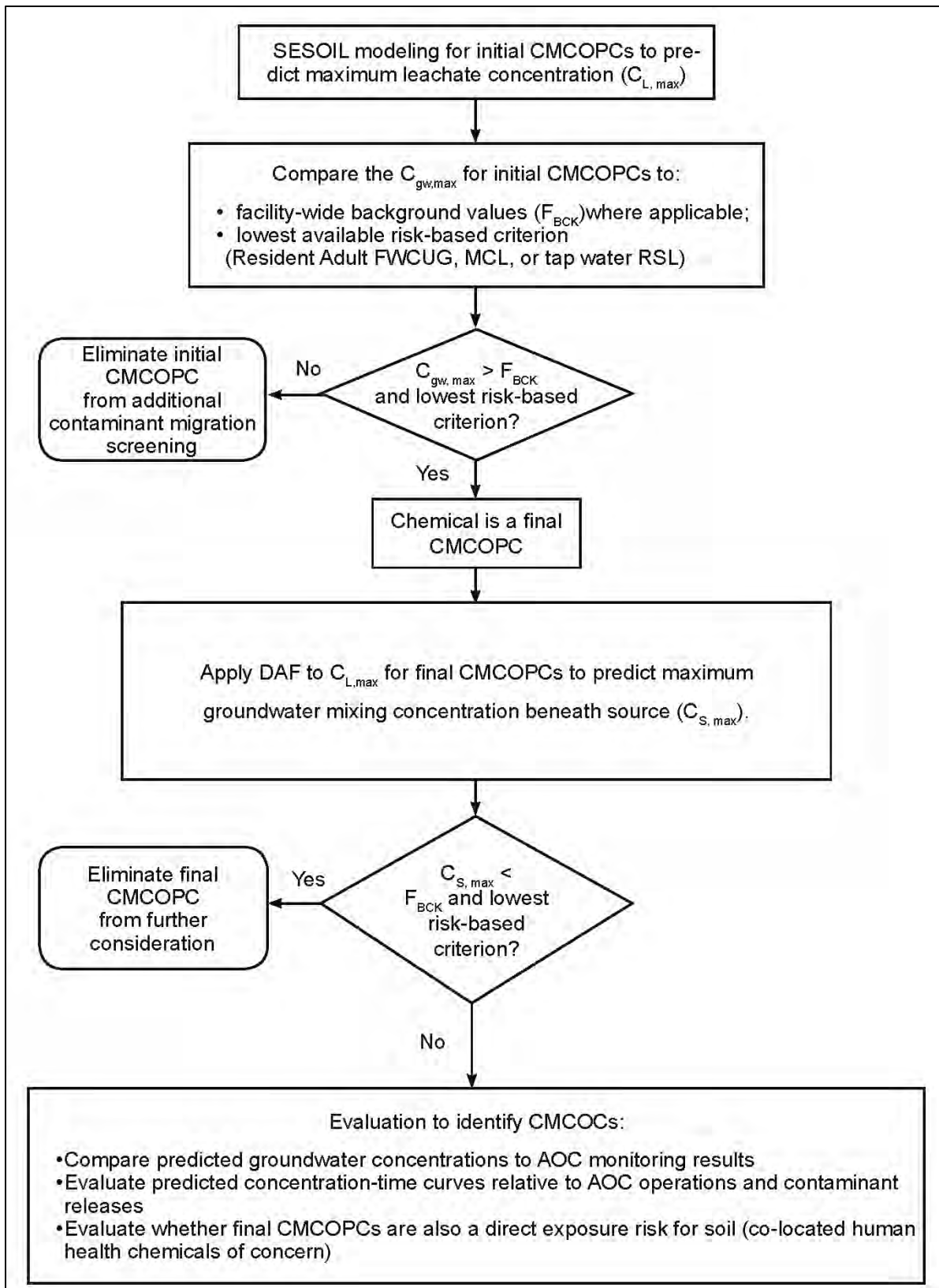


Figure E-2. Initial CMCOPCs Identified in Soil Screening Analysis for SESOIL Evaluation (continued)

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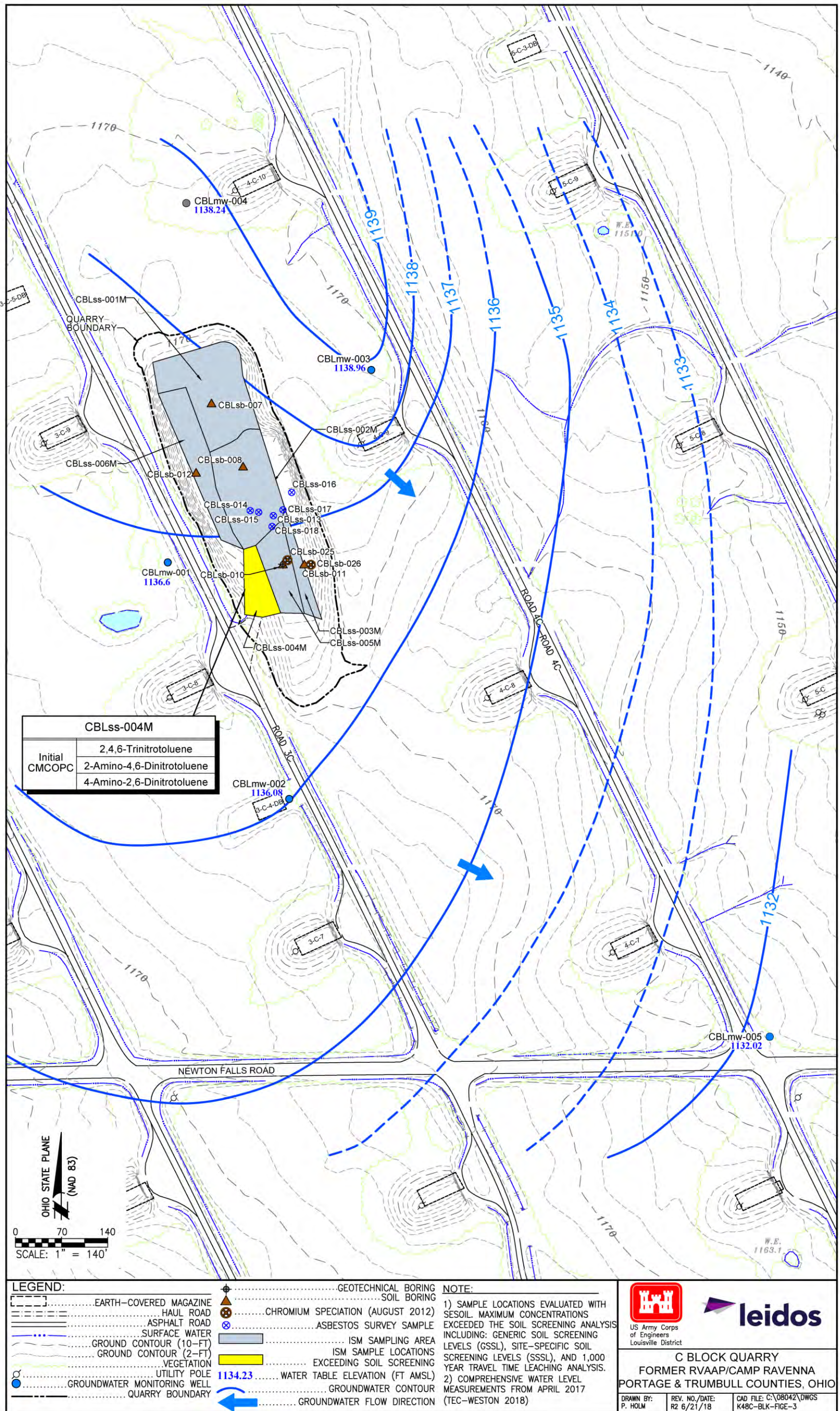


Figure E-3. Initial CMCOPCs Identified in Soil Screening Analysis for SESOIL Evaluation

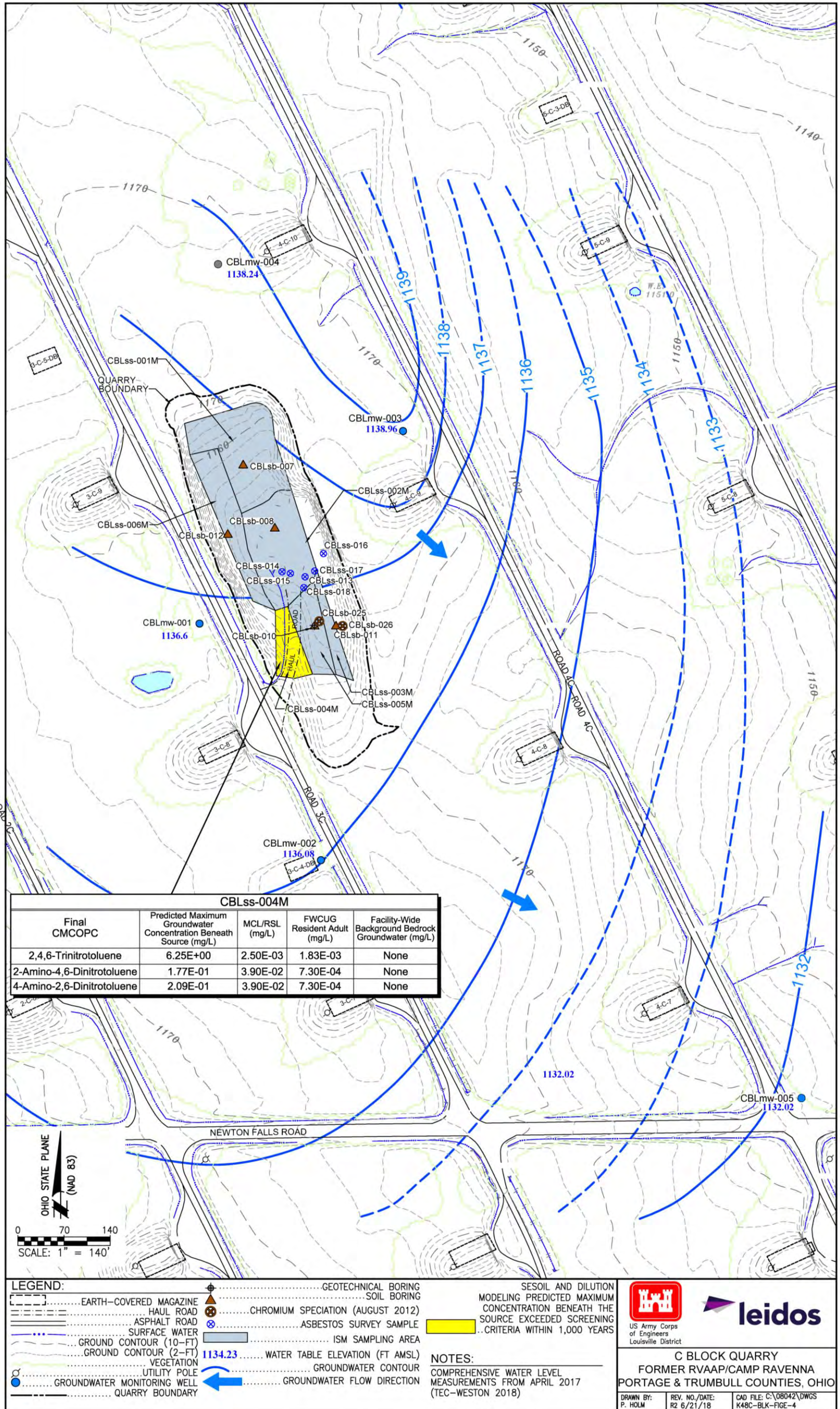


Figure E-4. Final CMCOPCs Identified for Further Weight-of-Evidence Evaluation Based on SESOIL and Dilution Modeling

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