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Contaminant Migration Model for the A-Area Miscellaneous Rubble Pile (731-6A) Operable Unit (U)

Tetra Tech, Inc. Alpharetta, GA

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EXECUTIVE SUMMARY

This report presents an updated model of vadose zone contaminant migration at the A-Area Miscellaneous Rubble Pile (731-6A) Operable Unit (ARP OU) at the Savannah River Site (SRS). The purpose of the modeling effort is to 1) identify constituents from the ARP OU that have the potential of entering groundwater within a reasonable regulatory timeframe at concentrations exceeding regulatory limits and 2) predict groundwater concentrations and arrival times at a downgradient receptor for the identified constituents. The model is an update to a similar study that was performed in 2000 as a part of the Resource Conservation and Recovery Act (RCRA) Facility Investigation/Remedial Investigation for the ARP OU. The previous screening identified trichloroethylene (TCE) and tetrachloroethylene (PCE) as constituents of concern and indicated that these constituents would result in groundwater contamination above regulatory standards at the nearest receptor. An updated model is necessary to evaluate concentrations and migration potential following remedial actions at the ARP OU.

The current study consisted of an update to the hydrogeologic conceptual model, performance of two levels of screening to identify constituents of concern, an update to the mathematical model, performance of predictive simulations to determine exposure times and concentrations for the constituents of concern, and the performance of sensitivity simulations to assess the effects of parameter, boundary condition, or conceptualization uncertainty on the predicted results. Many elements of the original hydrogeologic conceptual model were retained. The primary changes included: 1) a more detailed representation of localized stratigraphy obtained from lithology data for boring MSS12SB; 2) the need to evaluate only the Trenches Area, because other two areas have been successfully remediated; and 3) new source term concentrations from soil borings cored in July 2018. The primary migration mechanism of importance is dissolved transport of constituents of concern (COCs) through vadose (unsaturated) zone soils to groundwater. The physical and chemical processes affecting the fate and transport of dissolved COCs in the unsaturated zone include advection, hydrodynamic dispersion, molecular diffusion, adsorption, and degradation.

Simulations of contaminant transport through the vadose zone were completed using VZCOMML©, a multi-layer vadose zone contaminant migration modeling program developed by SRS. This program determines whether the waste-site contaminant concentrations are above the Tier 1 and Tier II limits and identifies COCs for more detailed site-specific analysis. Tier 1 screening involves modeling using the most conservative assumptions, including maximum constituent concentrations at the maximum sample depth (i.e., shortest travel time distance in the vadose zone to water table). A less conservative set of assumptions was used for Tier II analysis to impact groundwater at concentrations exceeding action levels within the evaluation time of 1,000 years. Results of the VZCOMML predictive modeling indicated that PCE and TCE would be below Maximum Concentration Limits (MCLs) at the downgradient receptor, which is a monitoring well located at the edge of the waste unit. Maximum predicted concentrations for PCE and TCE over the 1,000-year evaluation period are 12 to 13 orders of magnitude below MCLs at the receptor due to the large unsaturated zone transport distance (depth), comparatively low rates of flow, and first-order organic decay operating over long transport times.

Sensitivity analysis indicated that the predicted results are sensitive to fraction organic carbon, infiltration rate, retardation, and degradation rate. The least sensitive parameters include aquifer thickness, source length, and aquifer hydraulic conductivity.

The updated model indicates that TCE and PCE at the ARP OU Trenches Area no longer pose a threat to human health and the environment. Three primary factors have changed since the original modeling effort was performed nearly 20 years ago that lead to this result. First, active and passive SVE have removed volatile organic compound (VOC) mass and reduced concentrations in the vadose zone. Second, the updated modeling includes a greater level of discretization (five layers instead of two) and incorporates site specific data that account for thin layers of low hydraulic conductivity material. The greater level of numerical detail and stratigraphic consideration results in longer travel times and increase attenuation of constituents. Third, with a lower water table elevation, the vadose zone transport distance is greater, resulting in longer travel times and increased attenuation.

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LIST OF ACRONYMS AND ABBREVIATIONS

µg	micrograms
ARP	A-Area Miscellaneous Rubble Pile
bls	below land surface
C_{sat}	NAPL concentration limit
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cm	centimeters
CM COPCs	contaminant migration chemicals of potential concern
COC	constituent of concern
COPC	chemicals of potential concern
CPT	cone penetrometer technology
c_s	source/sink concentration
d	day
DAF	dilution attenuation factor
FFA	Federal Facilities Agreement
ft	feet
F_{oc}	fractional organic content
g	grams
HCM	hydrogeologic conceptual model
in	inches
K_d	Soil-water partition coefficient
kg	kilograms
K_{oc}	organic-carbon partition coefficient
L	liters
LLC	Limited Liability Company
LUC	Land Use Control
MCL	maximum contaminant level
m	meter
mg	milligrams
MLSSL	mass limited soil screening level
$MLSSL_{1/2}$	decay adjusted mass limited soil screening level
NAPL	non-aqueous phase liquid
OU	Operable Unit
PAH	Polycyclic aromatic hydrocarbon
PCE	tetrachloroethylene
RCRA	Resource Conservation and Recovery Act
REV	representative elementary volume
RG	Remedial Goal
RGO	Remedial Goal Option
SCDHEC	South Carolina Department of Health Environmental Control

SESOIL	Seasonal Soil Compartment Model
SRNS	Savannah River Nuclear Solutions
SRS	Savannah River Site
SSL	soil screening level
$SSLT_{1/2}$	decay adjusted soil screening level
SVE	soil vapor extraction
TCE	trichloroethylene
USC	Unit-specific compound
USEPA	United States Environmental Protection Agency
USNRC	United States Nuclear Regulatory Agency
VOC	volatile organic compound
VZCOMML	Vadose Zone Contaminant Migration Model Multi Layered
WSRC	Westinghouse Savannah River Company LLC
yr	year

1.0 INTRODUCTION

The A-Area Miscellaneous Rubble Pile (ARP) (731-6A) Operable Unit (OU) (U) is located in the northwest part of the SRS within A-Area and immediately east of M-Area (Figure 1-1). Beginning in the early 1950s, the area was used as a disposal location for construction debris and ash material (WSRC, 2000; SRNS, 2014). The ARP OU includes three subunits: (1) Piles Area, (2) Ash Area, and (3) Trenches Area (Figure 1-2). The selected remedial actions for each subunit were as follows: removal of contaminated soil followed by Land Use Controls (LUCs) for the Piles Area; LUCs for the Ash Area; and soil cover, active soil vapor extraction (SVE), and LUCs for the Trenches Area. The active SVE system transitioned to passive SVE in March of 2017.

In 1998, soil samples that were collected in native soils beneath the contaminated ash in the Trenches Area subunit and were below remedial action levels (RAL) for PCE (RAL = 0.656 mg/kg) and TCE (RAL = 0.0877 mg/kg). Previous vadose zone solute migration modeling at this unit (WSRC, 2000) applied the Seasonal Soil Compartment Model (SESOIL) to examine the fate and transport of COCs. Results of this modeling indicated either long (>1500 year) travel times to groundwater or groundwater concentrations at receptors being below regulatory limits for most constituents. However, the modeling indicated that PCE and TCE would exceed groundwater standards within 1,000 years.

To address remaining volatile organic carbon (VOC) impacts within the source active SVE, consisting of seven (7) SVE wells, was implemented to remove TCE and PCE primarily from the ash zone in the Trenches Area subunit. The active SVE system started full operation in 2004 and was transitioned to a passive SVE system in 2017. Figure 1-3 shows the location of the SVE system and twelve (12) vadose zone monitoring wells. The SVE system has removed more than 49 kilograms (kg [108 pounds]) of mass in the source zone (SRNS 2017; 2018). Since 2006, the concentrations of TCE and PCE in the soil gas were very low, indicating less mass in the ash source zone with concomitant reduced downward mass flux into the unsaturated zone. Source zone mass removal continues via extraction by the passive SVE system. In addition, the domed 0.3 m (1 ft) soil cover also limits infiltration, reducing the source mass flux from the ash zone to the unsaturated zone. A small vegetative cap was installed to improve performance of the shallow SVE wells in the vadose zone. This cap is not included in the model as its only purpose is SVE improvement with limited impact to overall infiltration into the unit compared to background conditions.

In July 2018, additional soil samples had localized concentrations of PCE and TCE above their remedial action levels in native soil at a depth of 4.6 m – 4.9 m (15 ft - 16 ft) bls. Because these sampling locations are different than previous locations, it is unclear whether these recent detections indicate improved delineation of historical impacts or more recent downward migration of contaminants into the native soil.

An update to the vadose zone contaminant transport model was conducted to evaluate residual soil contamination and determine if the contamination has the potential to migrate to groundwater and exceed groundwater action limits within a reasonable time frame. The update was needed to evaluate concentrations and migration potential following remedial actions at the ARP OU. The tasks associated with updating the model and analysis that were conducted and described in this report include:

- Refine the Vadose Zone Contaminant Migration Model Multi-Layered General Conceptual Design for the A-Area Miscellaneous Rubble Pile using characterization and monitoring data from historical and recent characterization and monitoring activities;

- Establish a reasonable and defensible Dilution Attenuation Factor (DAF), partition coefficients, mean travel time, decay rates, and saturation concentrations. Make groundwater contaminant migration predictions based on these parameters;

- Perform a screening analysis of model parameters and address model uncertainty;

- Use VZCOMML © to conduct a multi-layer vadose zone contaminant migration modeling evaluation; running contaminant transport simulations for the ARP OU;

- Develop a contaminant transport model for potential groundwater contamination and migration times of PCE and TCE.

- Document the groundwater contaminant migration model development and calibration processes, simulations performed, evaluations, and interpretations/results in an ARP OU modeling report and submit electronic copies of the report and files, data, and calculations.

Following this introduction, the report describes the original and current Hydrogeologic Conceptual Models in Section 2.0. The processes, data, and properties associated with the chemicals and hydrogeologic system are also described in this section. The contaminant screening and vadose zone modeling are described in Section 3.0. The modeling tool, VZCOMML, and details of it configuration and data input are presented. The results of both Tier 1 and 2 screening analyses are presented, followed by the results of the modeling for PCE and TCE. Finally, the report is summarized and conclusions presented in Section 4.0.

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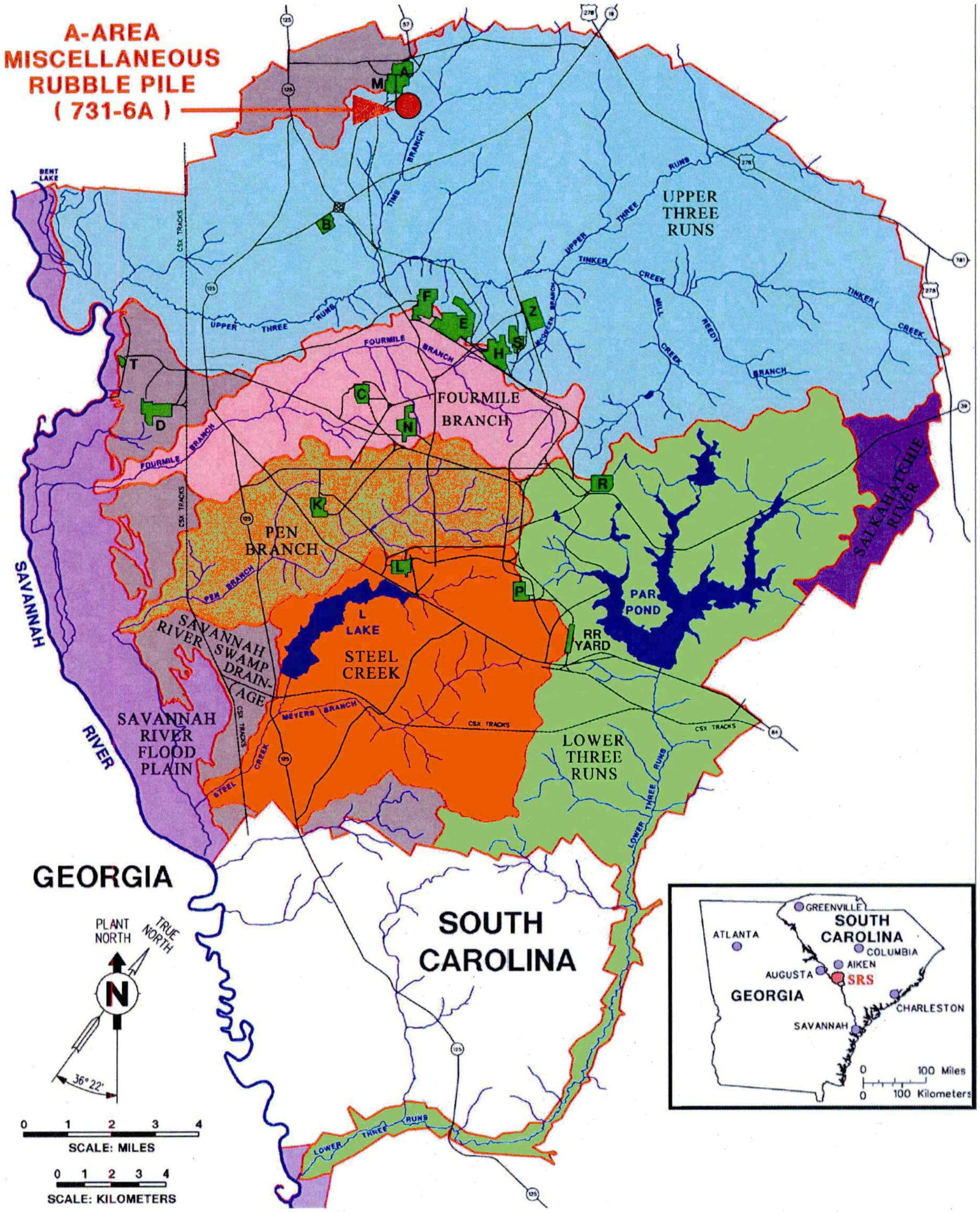

Figure 1-1. Location of ARP OU

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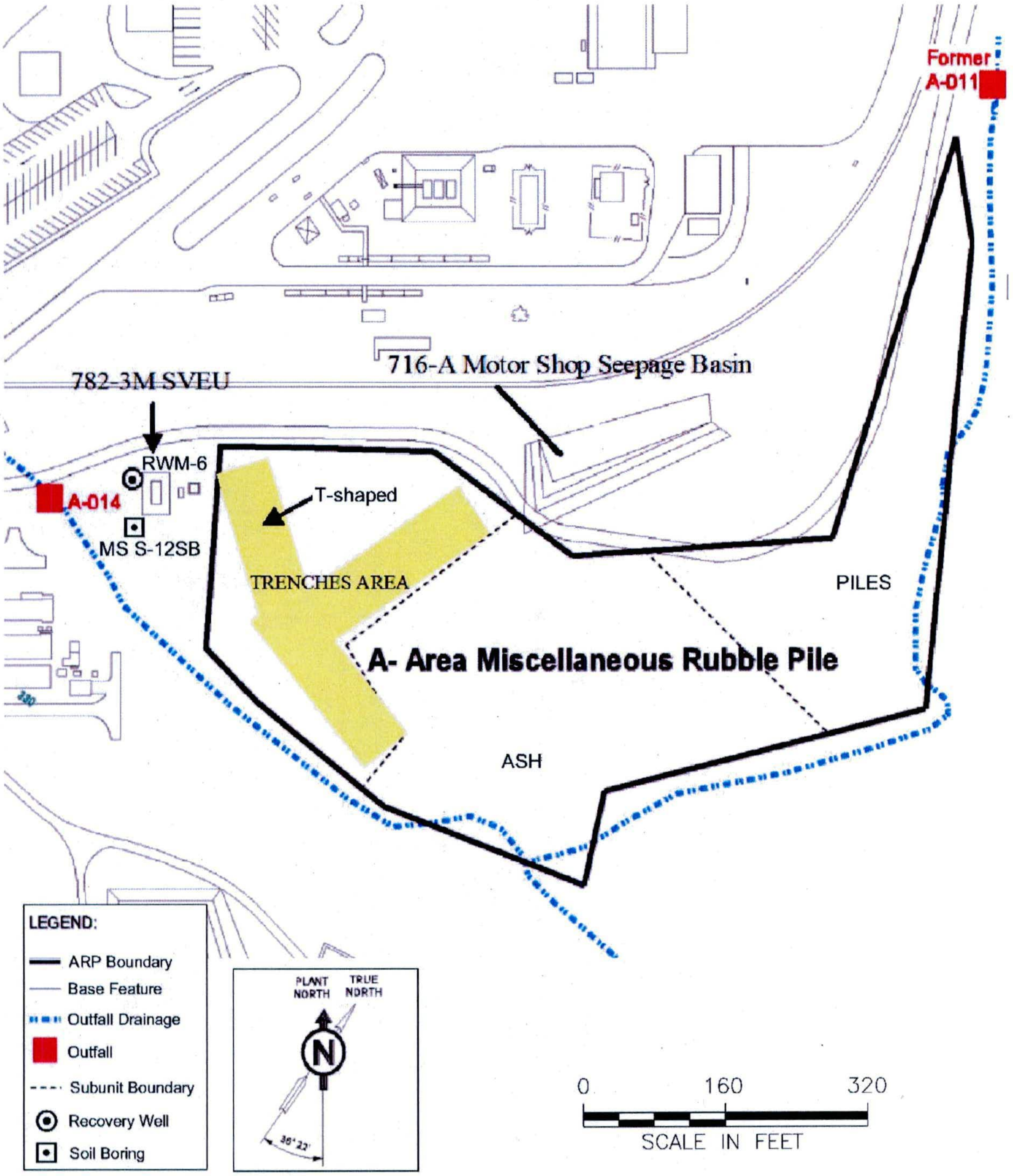

Figure 1-2. ARP OU (731-6A) Subunits

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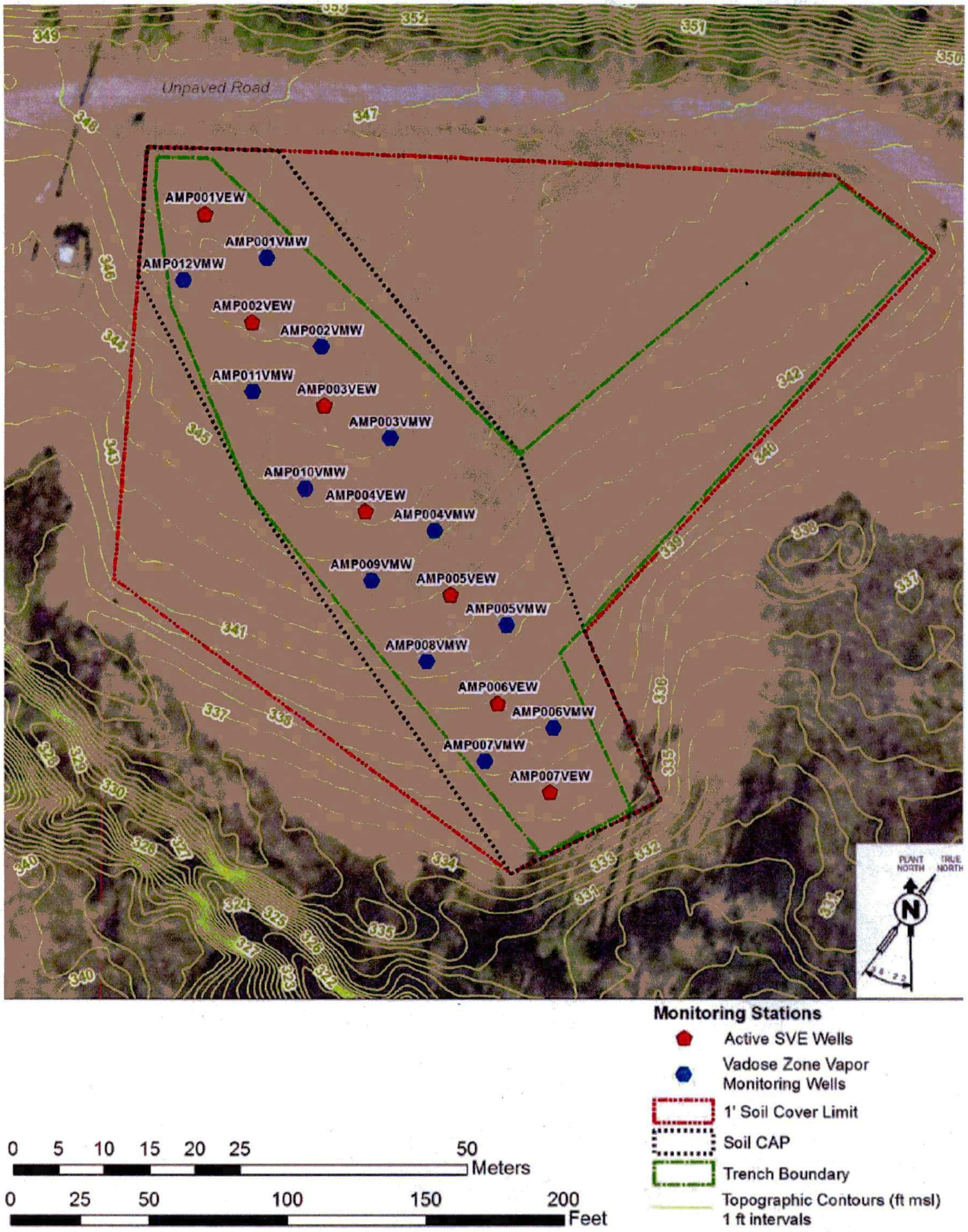

Figure 1-3 ARP OU SVE and Vadose Zone Monitoring Well Locations

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2.0 HYDROGEOLOGIC CONCEPTUAL MODEL

A hydrogeologic conceptual model (HCM) refers to a general description of the pertinent physical controls on ground-water and contaminant movement. The HCM presents known or expected site conditions that form a framework within which an investigation is developed and against which new data can be compared and interpreted. The HCM incorporates all the waste unit characteristics that constitute the problem being addressed (e.g., hydrogeologic features, primary contaminants and their properties, and potential human and ecological exposure scenarios). The HCM is specific to the domain of interest or representative elementary volume (REV). In this case the REV extends vertically from the top of the soil cover to the base of the mixing zone within the groundwater and horizontally to the limits of the waste unit. The predictive function of the HCM that is of primary importance to contaminant fate and transport analyses relies on known information and informed assumptions about the waste unit. With better quality of available information and greater the accuracy of assumptions, a more accurate HCM can be developed to describe the site, resulting in more reliable predictions. The HCM forms the basis of the mathematical model (sometimes just called the model), which solves equations for groundwater head and concentration specific points in space and time. The mathematical model is discussed in Section 3.

2.1 Original HCM

The original HCM was described in Section 2.0 of WSRC (2000) and is presented in Figure 2.1. The basic elements include waste contained in rubble, ash, and debris ash deposited on the ground surface (piles) or shallow subsurface (ash and trenches). The areas are each subjected to water derived from precipitation entering the waste at the surface. Contaminated surface and subsurface soils may leach contaminants into the groundwater. Various factors and properties control the release rate of contaminants to the vadose zone. Once in the vadose zone, contaminants are vertically directed downwards by gravity through the approximate 100 ft thick vadose zone. Attenuation of the leachate is controlled by properties of each of the contaminants and soils. Some of the more mobile and conservative (non-degrading) contaminants may reach the water table. There, contaminants mix with resident groundwater that is flowing (generally) horizontally. The depth of mixing forms the vertical dimension of the "mixing zone". The primary exposure point is the edge of the waste unit, which forms that lateral dimension of the mixing zone. The exposure point is depicted on Figure 2.1 as a well that removes water at the edge of the waste unit.

The original HCM considered each of the exposure units separately, despite the possibility of groundwater passing sequentially beneath the Piles Area, Ash Area, and Trenches Area. However, because COCs were identified for only one exposure unit and no PAHs were identified as COCs (WSRC, 2000), a cumulative assessment was not required.

2.2 Updated HCM

Figure 2-2 presents the updated HCM for this unit. Many elements of the original HCM are retained in the updated HCM. The primary changes include:

- A more detailed representation of localized stratigraphy, obtained from lithology data from boring MSS12SB.
- The need to evaluate only the Trenches Area, because the other two areas have been successfully remediated.
- New source term concentrations that are based on recent soil borings. These concentrations may reflect the effect of active and more recent passive SVE.

The primary migration mechanism of importance is dissolved transport of COCs through vadose (unsaturated) zone soils to groundwater. The expected site conditions and components of the HCM at this unit are briefly discussed below.

2.2.1 Infiltration and Surface Runoff

The potential for downward contaminant transport in the vadose zone begins with precipitation. Precipitation that falls on the unit may either infiltrate the shallow soil section or run off the unit. The degree to which the processes of infiltration and runoff occur across the SRS is variable and depends primarily upon precipitation, topography and the type and density of vegetation.

Infiltration into shallow soils is increased by increased precipitation, low or negative topographic relief (which limits losses to surface runoff), and sparse vegetation (which attenuates evapotranspiration). The average annual rainfall for the area over the last 20 years is 118.3 cm (46.78 in, SRNL, 2017), however a value of 122 cm (48 in, measured in 1991 at the Savannah River Technology Center gauging station in the A/M area) is used to be consistent with the previous SESOIL model. Therefore, the average annual infiltration is 43 cm (17 in), which is calculated by taking an annual rainfall of 122 cm (48 in) less 78 cm (31 in) of evapotranspiration (based on discussion below). This is a conservative value because it does not take into account water losses to surface runoff. No surface water runoff or seeps to adjacent streams was observed during site characterization. The ground surface at the unit is vegetated and infiltration is expected to be high.

2.2.2 Evapotranspiration

All infiltrated water does not provide recharge to groundwater; much of it is lost from the subsurface via evapotranspiration. The evapotranspiration varies seasonally with lower rates occurring during the winter and higher rates occurring during the summer. During periods of low rainfall in the summer, the net infiltration rate may be zero. The amount lost is also variable spatially, depending largely on the extent and type of vegetative cover. At SRS, the average amount of water lost to evapotranspiration is approximately 64 percent of the total precipitation (Parizek and Root, 1986).

2.2.3 Subsurface Flow System

The infiltrated water that is not lost to evapotranspiration is integrated into the subsurface flow system. The subsurface flow system is comprised of the vadose zone and the saturated zone. Percolation of infiltrated water to the water table is the primary source of recharge for the water table aquifer. The percolation rate (aquifer recharge rate) is controlled in part by vadose zone porosity and permeability. Beneath the unit, clayey sediments limit the rate of percolation due to their relatively low permeability. The average percolation rate through the vadose zone to the water table is 8.2 cm/year (3.2 in/year) (WSRC, 2000).

At the unit, the vadose zone ranges from land surface to a water table depth of 37.63 m (123.45 ft) below land surface (bls) at well MSS12B. It is composed primarily of interbedded sands, silty sands, sandy silts, and clays of the Dry Branch, Tobacco Road, and Altamaha Formations. Except for 4.6 m (15 ft) in Trenches area, clays and clayey sands dominate the vadose zone section from 0 to 6.4 m (0 to 21 ft) below grade; sands and silty sands dominate the section from 6.4 m (21 ft) to the water table. Though somewhat sandier than overlying layers, relatively low proportion of intergranular clay and silt, as well as interlayered clay beds, can result in substantial reductions in effective vertical hydraulic conductivity.

The water table aquifer represents the M-Area and "Lost Lake" aquifer zones of the Steed Pond Aquifer and is composed of silt and clay. Based on cone penetrometer technology (CPT) borings conducted under the Phase 2 investigation (WRSC, 2000), the water table aquifer consists of interbedded sands, silts, and clay of the Dry Branch and Santee Formations. Because of the strong vertical gradient in the M-Area aquifer zone, groundwater flow is primarily downward through the section. The M-Area aquifer zone is approximately 6.1 m (20 ft) thick and extends from the water table to the "green clay" confining zone at a depth of approximately 36.6 m (120 ft) bls. The "Lost Lake" aquifer zone underlies the "green clay" confining zone. It comprises the sands and clays of the Congaree and Fourmile Formations and is approximately 17 m (55 ft) thick at ARP. Downward flow from the M-Area aquifer zone is the primary source of recharge for the "Lost Lake" aquifer zone.

Groundwater at the A/M Area, which includes the ARP, is currently being addressed under a corrective action program. This remediation program was instituted in 1985 and consisted of a groundwater extraction and treatment systems (air strippers) supplied by networks of recovery wells. Groundwater beneath the unit is only slightly impacted by the remediation system in place, so the hydraulic gradient was set to pre-system installation values. Use of pre-recovery conditions provides a conservative estimate for the model as hydraulic gradient is smaller resulting in less dilution and higher groundwater concentrations.

2.2.4 Release Mechanisms

For the purposes of this analysis, the primary release mechanism at the unit is infiltration with leaching to groundwater. Water infiltrating through waste at the surface and contaminated surface and subsurface soils may leach contaminants into the groundwater. The factors that affect leaching rate include a contaminant's solubility, soil-water partition coefficient (K_d), and the amount of infiltration. Whether it is a contaminant's K_d or solubility that controls leaching depends on whether leaching is solubility-controlled or sorption-controlled. Insoluble compounds will remain as a mixture and will not by definition be subject to leaching. leaching. The contaminants detected at the unit generally do not form insoluble compounds in the natural environment, so sorption processes and K_d will have the greatest effect on leaching. For the residual mass in the ash layer, including oily waste, primarily hydrophobic constituents remain in this source zone that will be relatively immobile with high K_d values. Those contaminants with small K_d values will be leached more effectively than those with larger K_d values.

The physical and chemical processes affecting the fate and transport of dissolved COCs in the unsaturated zone include advection, hydrodynamic dispersion, molecular diffusion, adsorption, and degradation. These processes change the mass and distribution of dissolved COCs in the unsaturated zone and water table aquifer, as described below:

- ***Advection*** is the migration of dissolved COC via moving groundwater. Advection via infiltration in the unsaturated zone is typically the dominant factor in downward transport of dissolved COCs.

- ***Hydrodynamic dispersion*** is a physical process whereby dissolved constituents spread out at the pore-scale level. This causes some COCs to spread downward faster than the average infiltration velocity in the unsaturated zone.

- ***Molecular diffusion*** is a physical process whereby molecules move from an area of higher concentration to an area of lower concentration. The rate of molecular diffusion is typically dwarfed by advective and dispersive forces. However, molecular diffusion is often a significant factor in the pore-scale transfer of COC mass that is trapped in lower permeability zones that have very slow advective movement.

- ***Adsorption*** is a chemical process whereby dissolved COCs react with the surfaces of solids. Strongly adsorptive materials often have slow rates of desorption. Several laboratory studies have shown that the mass of organic contaminants adsorbed to soil is proportional to the amount of organic carbon in the soil (e.g., Karickhoff, 1985) under equilibrium conditions.

- ***Degradation*** processes are biological and chemical processes that decrease the mass of dissolved constituents. These processes include biodegradation, photolysis, oxidation-reduction, and hydrolysis. They are generally grouped into either biologic or abiotic (chemical) degradation processes. Both PCE and TCE degradation can be approximated using a first-order reaction. For a given percolation rate, those contaminants with long half-lives have a greater potential for contaminating groundwater than those with shorter half-lives.

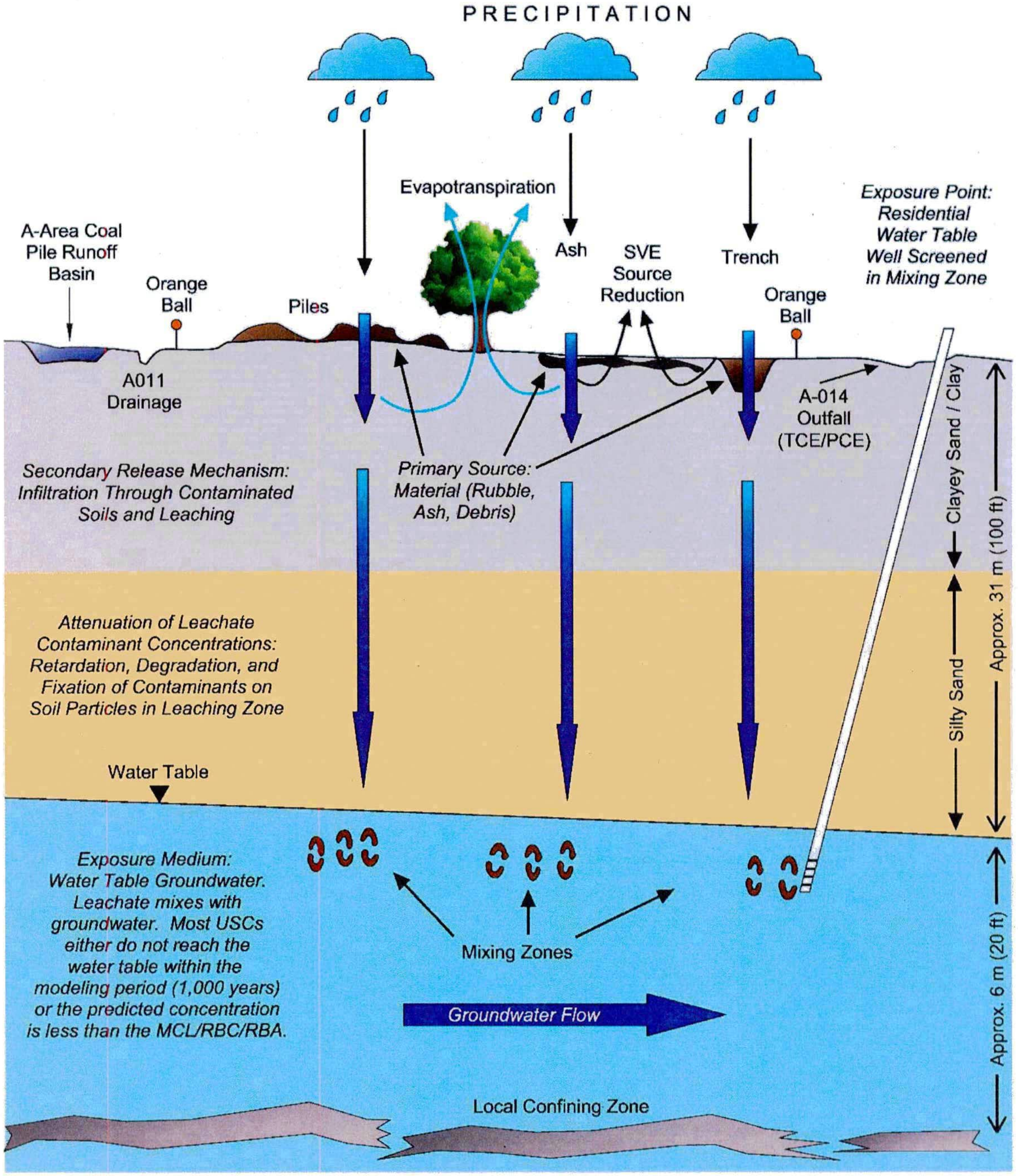

Figure 2-1. Original Contaminant Remediation and Migration Conceptual Model

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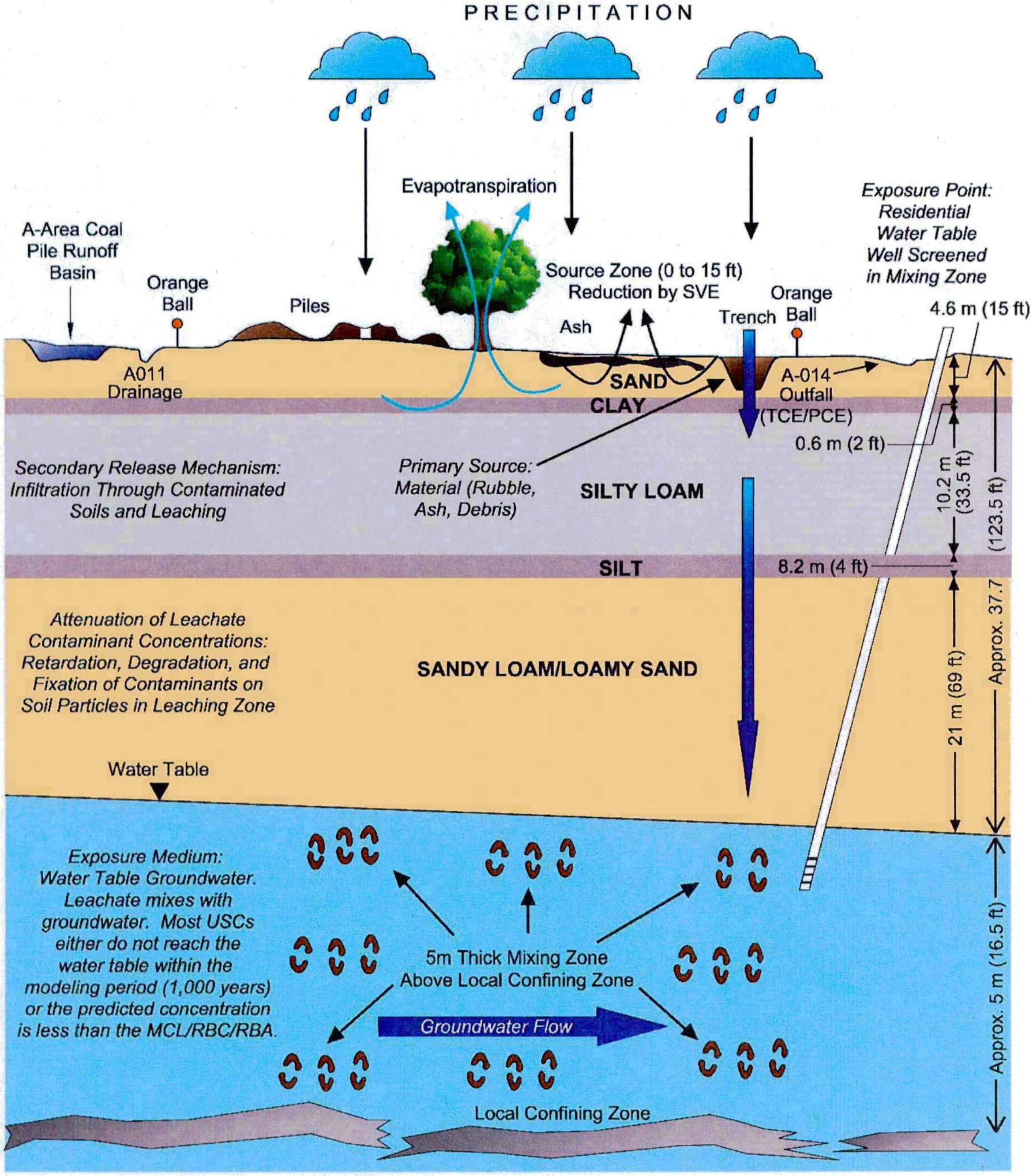

Figure 2-2. Updated Contaminant Remediation and Migration Conceptual Model

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3.0 CONTAMINANT SCREENING AND VADOSE ZONE MODELING

This section describes the selected model, construction of the model based on the updated HCM, Tier I and Tier II soil screening analyses, and subsequent contaminant migration analysis that is performed on constituents that are retained based on the screening analyses. A common platform, VZCOMML, is used for both sets of analyses, which is described below.

3.1 VZCOMML Modeling Tool

Based on the HCM and available data, the VZCOMML (Version 4.0) model (Rucker, 2011) was chosen to perform both the screening and contaminant migration modeling analyses for the ARP Trenches Area Subunit. The VZCOMML model calculates the Soil Screening Level (SSL) and groundwater concentration for any analyte on the new US EPA Target Analyte List, Target Compound List (TAL/TCL), or radionuclide list (221 analytes in total). The software automatically compares waste-site soil contaminant concentrations with the calculated SSL limits and determines whether the waste-site contaminant concentrations are above the Tier I and Tier II SSLs (USEPA, 1996). The software also compares waste-site soil contaminant concentrations to calculated non-aqueous phase liquid (NAPL) threshold concentrations in soil media as part of the Tier I screening.

The model was designed to meet five objectives: 1) to be utilized as a detailed waste-site specific model for vadose zone contaminant fate and transport analysis required under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA); 2) to perform contaminant fate and transport analysis in a consistent manner that complies with the protocols specified by US EPA, Region IV, South Carolina Department of Health and Environmental Control (SCDHEC), and the United States Department of Energy (US DOE); 3) to calculate site-specific SSLs; 4) to evaluate the effectiveness of remedial alternatives by allowing the user to modify infiltration rates, aquifer hydraulic parameters, hydraulic soil layer functions that influence contaminant transport time and concentration; and 5) minimize technical labor required to perform a complex and robust contaminant migration analysis.

VZCOMML operates in a Microsoft Excel workbook comprising 22 worksheets. The first worksheet documents the equations used in the model, the second is a linked menu of worksheets providing simple access to model input and results worksheets, the third illustrates the VZCOMML conceptual model, and the fourth presents the USDA soil classification ternary diagram and soil physical and hydraulic properties. The next three worksheets are organized for input of dilution factor parameters, pore-water velocity (groundwater velocity) parameters, and physical data about the system such as depth to the water table, evaluation period, bulk density, and fraction organic carbon.

Worksheets labeled 4(a), et seq., are organized by type of contaminant and allow input of measured concentrations in the source soils, measured or assumed values of other parameters such as Henry's Law constant, K_{oc}, solubility limit, and others, and intermediate computations of factors used elsewhere in the model. Separate worksheets are included for VOC, SVOC, pesticides, metals, and radionuclides. Each of the five input worksheets has a corresponding results worksheet and a worksheet to calculate soil saturation limits and NAPL concentration limits (C_{sat}). Only the worksheets for VOCs were used for the ARP Trenches area simulations.

The model is a combination of independent analytical modules whose outputs are linked to logic arguments and to numerical outputs of all the other modules. There are five distinct modules. The Dilution Attenuation Factor (DAF) and Mixing Zone Module calculates the DAF and mixing zone depth using analytical equations in USEPA (1996). The Pore Water Velocity Module calculates pore-water velocity, soil moisture content, air-filled porosity, water-filled porosity, travel times through a multi-layer soil column, and constructs a layered soil column. The hydrological characteristics, including hydraulic conductivity, layer thickness, total porosity, effective porosity, and layer hydraulic functions are user-defined variables for up to five homogenous layers which are assembled into a heterogeneous soil column. The Tier I screening module automatically screens total contaminant concentrations from the waste site source area against two calculated Tier I SSLs and a soil NAPL limit (C_{sat}) value for each analyte and automatically lists analytes that exceed the screening logic.

The Result Module is the most sophisticated component of the model. It evaluates three fundamental logic criteria established in the US EPA Soil Screening Guidance and SRS Federal Facilities Agreement (FFA) protocols for contaminant migration to groundwater. The criteria include: (1) comparison of the calculated groundwater concentration to the action limit; (2) comparison of the retarded, mean travel time for a contaminant to reach the aquifer to a user-defined transport evaluation time; and (3) comparison of the waste site contaminant concentration to the mass limited soil screening limit (MLSSL). This module also computes the retardation factor, retarded mean travel time, and groundwater concentration for each analyte. The Result Module contains the action level, MCL, or SSL. The module will screen the estimated groundwater concentration for each analyte against its respective action level, and then automatically list all analytes that fail the screening. The Result Module calculates four different types of SSLs: (1) decay-adjusted SSL ($SSLT_{1/2}$); (2) $MLSSLT_{1/2}$, 3) default Tier I SSL, and 4) default Tier I MLSSL. The SSLs are suitable for use as Remedial Goal Options (RGOs) or Remedial Goals (RGs). Calculations are simultaneous for all 221 analytes if the required inputs are provided.

3.2 Model Construction

Based on the updated HCM, the VZCOMML model was constructed using available site data including detailed lithologic information from soil borings in the unsaturated zone. Based on the soil boring logs in and near the trenches area subunit including MSS12SB (Figure 1-2), the subsurface geology was divided into five geologic layers with distinct thicknesses assigned for each layer. The vertical hydraulic conductivity of each layer was estimated based on its observed lithology and USDA soil classification. Additional model input parameters were assigned based on site-specific data or literature values. The details of the model layers and key model input parameter values are discussed below in this section.

3.2.1 Model Layers

VZCOMML simulates the vertical migration of contaminants through the vadose zone. A contaminant transport model was generated using lithology information obtained from soil boring MSS12SB (Table 3.1). The soils collected from boring MSS12SB consist of beds of fluvial and marine sands, silts, and clays that can be aggregated into four reasonably well-defined soil beds beneath a source bed (Figure 3-1). The source bed (model layer 1) consists of 4.6 m (15 ft) of ash. The hydraulic properties of the ash in the source area are unknown. As a conservative measure the ash source bed was simulated as sand.

Model layer 2 corresponds to a 0.61-m (2-ft) thick bed of friable silty clay (silty clay by the USDA classification) with “oil”. Fine grain sediments or soil may be retardants to groundwater flow if the soil is fully saturated with oil. If oil is present only as grain coatings it may retard transport of dissolved organic chemicals because of interactions between the dissolved chemicals and carbon on the grains. Model layer 2 was simulated as a silty clay and used the SESOIL baseline study value for fraction organic carbon (F_{oc}).

Model layer 3 corresponds to a 10.2-m (33.5-ft) thick bed of sandy silt (USDA silty loam), model layer 4 corresponds to a 1.2-m (4-ft) thick bed of laminated silty clay loam, and model layer 5 corresponds to a 21-m (69-ft) thick sequence of interlayered sand and silty sand simulated as sandy loam.

3.2.2 Key VZCOMML Model Input Parameters

Soil hydraulic properties in the VZCOMML model are from the USDA or estimated values obtained from the USNRC and USEPA (Table 3.2). The model allows site-specific input of soil hydraulic properties, but as a conservative measure the USDA values for hydraulic conductivity were used because they are larger than values reported for boring MSS12SB (Table 3.1) and consequently will conservatively overestimate the rate of groundwater flow and contaminant transport.

Soil textures and thicknesses are data assigned by the user from site-specific lithologic information. Soil properties are assigned for the soils of each model layer by VZCOMML from values reported by the USDA. Site-specific user input, and model calculated data are summarized in Table 3.3. User assigned values for source length parallel to aquifer gradient, infiltration rate through vadose zone, aquifer saturated horizontal hydraulic conductivity, horizontal hydraulic gradient in the aquifer, average annual precipitation, fraction organic carbon in source layer, were provided by the SRS based on site conditions. Aquifer thickness, depth to bottom of source zone, and thickness of mixing zone were determined based on lithology and measurement of depth to water below land surface in monitoring well MSS12SB, supplied by the SRS and source soil PCE and TCE concentrations are from sampling results in 2018.

Table 3-1. Vadose zone soils properties and corresponding VZCOMML model layers.

VZCOMML		**MSS12SB Soil Description**	**Top (ft bgs)**	**Bottom (ft bgs)**	**USDA class**	**K (ft/d)**	***Kv (ft/yr)**
Model Layer	**Soil Zones**						
1	Source (~0-15')	ASH (modeled as Sand)	0.0	9.0	SL	2.068	62
2	Clay (~2')	CLAY - silty	9.0	17.0	SiC	0.071	26
3	Silty Loam (~33.5')	SILT - sandy (30-40%), trace clay	17.0	20.0	SiL	1.079	483
		SILT - sandy (30-40%), trace clay	20.0	25.5	SiL	1.079	
		SAND - silty (30%) vf-f sand	25.5	27.0	LS	4.855	
		SILT - sandy, trace clay	27.0	32.0	SiL	1.079	
		SILT - clayey, trace vf sand	32.0	37.0	SiL	1.079	
		SILT - thin clay laminations, trace vf sand	37.0	40.0	SiL	1.079	
		SAND - silty (30%), clayey	40.0	47.5	SL	2.068	
		SAND - silty (30%), clay (10%)	47.5	50.5	SL	2.068	
4	SiCL (~4.0')	SILT - thin clay laminations, trace vf sand	50.5	54.5	SiCL	0.118	43
5	Sandy Loam / Loamy Sand (~69')	SAND - silty (30%)	54.5	60.5	SL	2.068	387
		SAND - silty (30-40%), trace clay	60.5	67.0	SL	2.068	
		SAND - silty (15%)	67.0	74.5	S	16.449	
		SAND - silty (20-30%), clayey	74.5	80.0	SCL	0.359	
		SAND - silty (10-15%)	80.0	87.5	LS	4.855	
		SAND - silty (10-15%)	87.5	92.0	LS	4.855	
		SAND - silty, clayey	92.0	97.5	SCL	0.359	
		SAND - silty	97.5	101.0	LS	4.855	
		SAND - clayey, clay/silt matrix	101.0	104.5	L	0.540	
		SAND - silty (30%), clayey	104.5	110.5	SCL	0.359	
		SAND - silty (10-15% to 20-30%)	110.5	117.5	LS	4.855	
		SAND - silty (10-15%)	117.5	120.0	LS	4.855	
		SAND - silty (10-15%)	120.0	125.0	LS	4.855	

* interval weighted mean

VZCOMML assigns default values for several parameters that can be changed by the user. Default values for the parameters are preloaded by VZCOMML from literature values for organic carbon partitioning coefficient, VOC decay/degradation half-life, dimensionless Henry's Law constant, and solubility limit.

Table 3-2. Properties of the 5 layers of the VZCOMML model.

Model	Soil Texture	Parameter	Parameter Value	Units
1	Sand	Thickness	15	feet
		Total Porosity	0.43	v/v
		Effective Porosity	0.38	v/v
		Sat. Hydraulic Conductivity	6004	ft/yr
		Moisture Content	0.17	%
		Pore-Water Velocity	1.51	ft/yr
		Travel Time	9.95	years
2	Silty Clay	Thickness	2	feet
		Total Porosity	0.36	v/v
		Effective Porosity	0.289	v/v
		Sat. Hydraulic Conductivity	26	ft/yr
		Moisture Content	0.2968	%
		Pore-Water Velocity	0.88	ft/yr
		Travel Time	2.26	years
3	Silty Loam	Thickness	33.5	feet
		Total Porosity	0.45	v/v
		Effective Porosity	0.38	v/v
		Sat. Hydraulic Conductivity	394	ft/yr
		Moisture Content	0.26	%
		Pore-Water Velocity	1	ft/yr
		Travel Time	33.55	years
4	Silty Clay Loam	Thickness	4	feet
		Total Porosity	0.43	v/v
		Effective Porosity	0.342	v/v
		Sat. Hydraulic Conductivity	43	ft/yr
		Moisture Content	0.3264	%
		Pore-Water Velocity	0.80	ft/yr
		Travel Time	4.98	years
5	Sandy Loam	Thickness	69	feet
		Total Porosity	0.41	v/v
		Effective Porosity	0.35	v/v
		Sat. Hydraulic Conductivity	755	ft/yr
		Moisture Content	0.22	%
		Pore-Water Velocity	1.19	ft/yr
		Travel Time	57.86	years

3.3 Soil Screening Results

In this section, results of the Tier I and Tier II soil screening are presented for the ARP Trenches Area Subunit. As shown in the flow chart for the soil screening process (Figure 3-2), contaminant fate and transport analyses involve a series of screening steps to define the contaminant migration chemicals of potential concern (CM COPCs). After CM COPCs were identified through the screening process using VZCOMML, their fate and transport in the unsaturated zone were further evaluated using the VZCOMML model. The Tier I and Tier II screening steps and modeling procedure are discussed below in this section.

3.3.1 Tier I

Based on the historical and recent soil sampling data collected in 2018 at the trenches area subunit, the Tier I screening process in VZCOMML was applied to compare the concentrations of unit-specific compounds (USCs) to source-specific and mass limit SSLs. As discussed in EPA (1996), the Tier I screening process provides a highly conservative assessment based on generic assumptions. The SSL calculation assumes a set of conditions representative of migration of chemical constituents through the vadose zone to the groundwater pathway. The SSLs were calculated to be protective for human health exposure to groundwater (EPA 1996). In general, if a contaminant concentration in soil was below the SSL and there was no significant ecological receptor of concern, then no further study or action was warranted for that constituent. The groundwater pathway is incomplete for all ecological receptors; this in turn indicates that there is no significant groundwater ecological receptor of concern. Based on soil sampling data collected at the site, the results of the Tier 1 screening are shown in Figure 3-3. This figure presents the output from the Result Model of VZCOMML and includes both source-specific and mass limit SSLs. The results of the Tier I screening identified the following COPCs: methyl bromide, chloroform, methyl chloride, dibromochloromethane, PCE, and TCE.

3.3.2 Tier II

As shown in Figure 3-4, the Tier II soil screening process was applied to examine the COPCs in Section 3.3.1 that did not pass the Tier 1 soil screening process. The Tier II screening processes includes site-specific details and more realistic simulation results for COC transport. As shown in Figure 3-4, PCE and TCE were the only chemicals in soil that exceeded the Tier II $MLSSL_{1/2}$ levels. The VZCOMML model was therefore applied to examine the fate of PCE and TCE during transport in the vadose zone and mixing with groundwater. As discussed in the HCM, PCE and TCE undergo physical, chemical, and biological processes that tend to decrease the contaminant concentration at the receptor point, which is a monitor well located at the downgradient edge of the source zone.

Table 3.3 summarizes the model input parameters that were used in the VZCOMML modeling analyses. Site-specific data was used whenever available. Conservative model input parameters where used for less certain model parameters. For example, a conservative value of 10 years was used for the degradation half-life of PCE and TCE (Howard et al, 1991; Aronson and Howard, 1997; USGS, 2006). The mixing processes in groundwater may be approximated by the use of a DAF, which is the ratio between the leachate concentration and the predicted eventual groundwater concentration. Based on the site-specific model input data in Table 3.3, a DAF value of 2.7 was estimated using the VZCOMML model.

The only process included in the DAF calculation is dilution due to mixing in groundwater; this is a conservative approach which excludes processes such as biological degradation, hydrolysis, ion exchange, and precipitation.

Table 3-3. Site-specific user input, and model calculated data.

Parameter	Value	Units	Source[1]
Dilution factor module worksheet			
Source length parallel to aquifer gradient	400	feet	Ss
Infiltration rate through vadose zone	0.2624	feet/year	Ss
Aquifer sat. horizontal hydraulic conductivity	2555	feet/year	Ss
Aquifer thickness	16.5	feet	Ss
Horizontal hydraulic gradient in aquifer	0.0042	feet/feet	Ss
Mixing zone depth	16.5	feet	Vc
Dilution attenuation factor	2.69	unitless	Vc
Average Annual Precipitation for Area of Interest	4.0443	feet/year	Si
Geotechnical/physical data worksheet			
Depth to Bottom of Source	15	feet	Si
Exposure Duration	70	years	Ss
Bottom of Source Zone to Groundwater	108.5	feet	Si
Evaluation Time	1000	Years	Ua
Bulk Density	1.82	kg/L	Ss
Fraction of Organic Carbon in Source Layer	0.00266	unitless	Ss
Input worksheet[2]			
Soil-Water partitioning coefficient	155 / 166	L/kg	Vd
VOC decay/degradation half-life	10.0 / 10.0	years	Vd
Dimensionless Henry's Law constant	0.754 / 0.422	unitless	Vd
Solubility limit	200 /1100	mg/L	Vd
Results worksheet			
Source soil concentration	4.39 / 4.22	mg/kg	Si
Retardation coefficient	4.8 / 5.1	unitless	Vc
Mean travel time	462 / 488	years	Vc
Predicted groundwater concentration	$4.13\text{x}10^{-12}$ / $6.61\text{x}10^{-13}$	µg/L	Vc

Notes:

[1] Si = measured site values
Ss = values from SESOIL (WSRC 2000 baseline risk study)
Vc = VZCOMML calculated values
Vd = VZCOMML default values
Ua = user assigned value consistent with EPA recommendation

[2] Values shown are for PCE and TCE using format PCE / TCE

3.4 Model Simulation Results

The VZCOMML model was constructed based on available site-specific data and a reasonably conservative modeling approach. As discussed above, the VZCOMML modeling incorporated new PCE and TCE soil concentration data that was collected in July 2018. Lithology thickness and soil classification used in the VZCOMML model were based on soil boring MSS12SB. The infiltration rate was estimated through calibration of the SESOIL model (WSRC, 2000). Results of the VZCOMML modeling indicated that PCE and TCE were below MCLs at the downgradient receptor, which is a monitoring well located at the edge of the waste unit. Additional sensitivity analyses of the VZCOMML model results are discussed below.

3.5 Sensitivity Analysis

Sensitivity analyses are performed on groundwater models to assess the effects of parameter, boundary condition, or conceptualization uncertainty on the predicted results. The procedure generally relies on changing a single model variable (parameter, aquifer property, or boundary condition) by a selected amount within a reasonable range of certainty and comparing the sensitivity simulation result to the calibrated model results. This procedure is repeated several times, where independent changes are made to assess lower and higher ranges of uncertainty for a suite of parameters, boundary conditions, or conceptualizations.

VZCOMML predicts mean transport times from the source bed to the water table to be more than 460 years, which amounts to more than 40 half-lives of organic degradation and predicted concentrations for PCE (4.13×10^{-12} µg/L) and TCE (6.61×10^{-13} µg/L) are very low in the aquifer. As expected then, the VZCOMML model of the ARP OU Trenches Area is significantly sensitive only to variations parameters that directly influence rate of transport from the source to the aquifer. Due to the large unsaturated zone transport distance from the base of the source bed to the aquifer, the relatively low rate of downward flow provides sufficient time for degradation to limit downward plume transport. Figures 3-5 and 3-6 present the sensitivity of the model results to key model input parameters including infiltration rate, vadose zone groundwater velocity, first-order degradation half-life, organic carbon (F_{oc}), retardation coefficient, and mixing zone thickness.

Even though some parameters are sensitive in the sense of value changes effecting changes in predicted concentration, no value of any parameter except degradation half-life and infiltration rate through the soil layer can cause groundwater concentration to exceed MCL. The infiltration rate through the vadose zone must exceed approximately 0.52 m/yr (1.7 ft/yr) to cause PCE to exceed its MCL and 0.55 m/yr (1.8 ft/yr) to cause TCE to exceed its MCL. Such large values for infiltration through the vadose are extremely unlikely since current estimates for infiltration in the Aiken area are approximately 76 mm/yr (3 in/yr) (SCDNR, 2009). For degradation half-life, the respective values are 77 and 81 years. Those values are very much greater than the already conservative 10-year half-life used in the model (USGS, 2006). The relative sensitivity of key flow, transport, and attenuation parameters in VZCOMML is summarized in Table 3.4 and illustrated in Figures 3-5 and 3-6.

Table 3-4. Relative sensitivity of key flow, transport, and attenuation parameters

Parameter	Modeled value[1]	Relative Sensitivity[2]	Influence[3]	Rank
Fraction organic carbon in source layer (wt/wt)	0.00266	4.57	T	1
Infiltration rate through vadose zone (ft/yr)	0.262	3.40	F	2
Retardation coeff. - avg. of PCE & TCE (unitless)	5	2.86	T	3
Half-life (degradation or decay) $T_{1/2}$ VOC (years)	10	2.71	A	4
Mixing zone thickness (feet)	16.5	2.57	A	5
Organic carbon partitioning coefficient - K_{oc} (L/kg)	160.5	1.84	T	6
Vert. mean non-retarded vadose zone velocity (ft/yr)	1.158	1.78	F	7
Horizontal gradient in aquifer (ft/ft)	0.0042	1.60	A	8
Dilution attenuation factor (unitless)	2.69	1.24	A	9
Aquifer thickness (feet)	16.5	1.17	A	10
Source Length (feet)	400	1.04	A	11
Aquifer hydraulic conductivity - K_h (ft/yr)	2555	1.00	A	12

Notes:

[1] arithmetic mean of values where TCE and PCE differ

[2] negative inverse log of slope of PCE & TCE concentration vs parameter at modeled value. Relative sensitivity shown normalized to lowest value

[3] A - attenuation/degradation/dilution; F - groundwater flow; T - transport

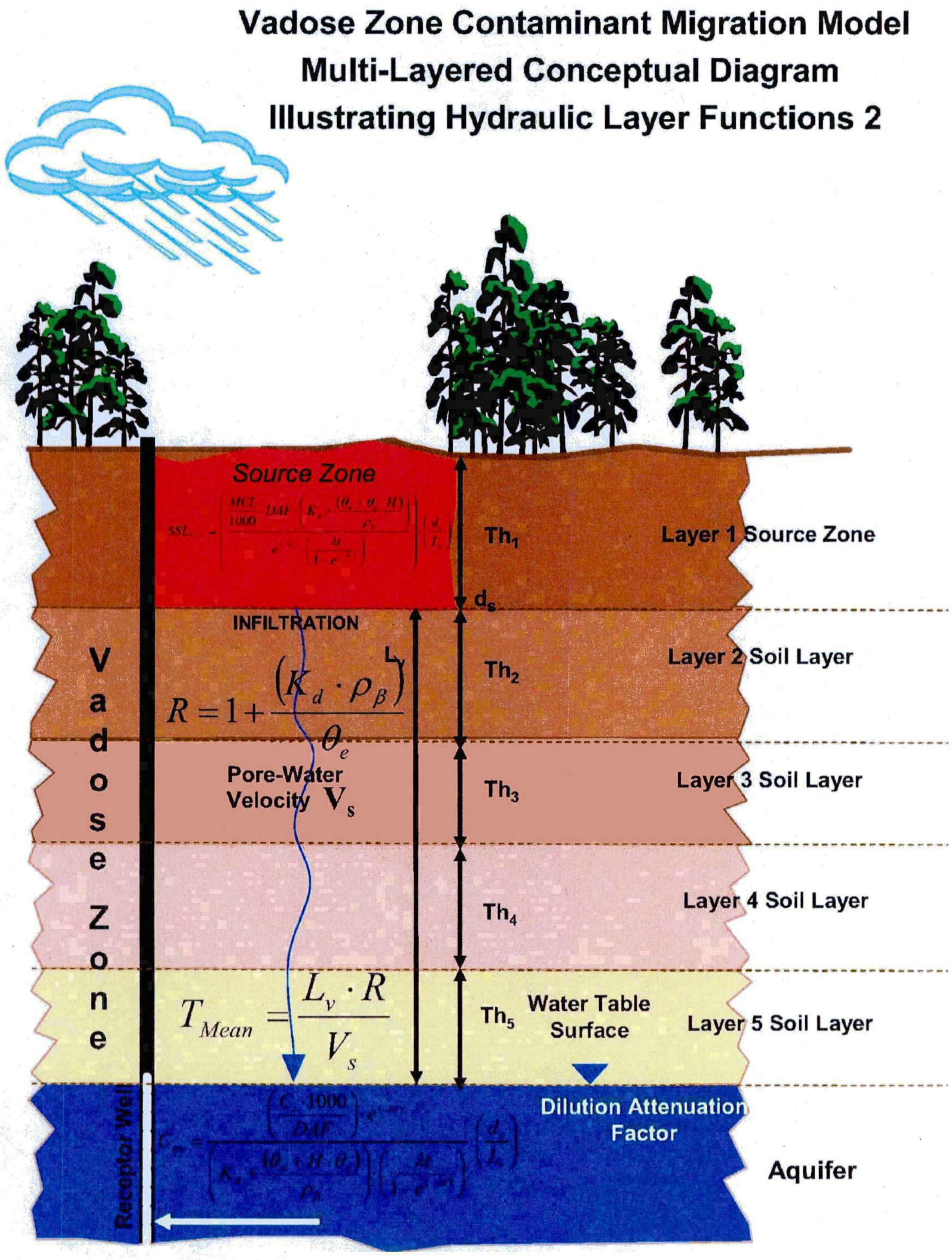

Figure 3-1. 5-layer VZCOMML model (Rucker 2011).

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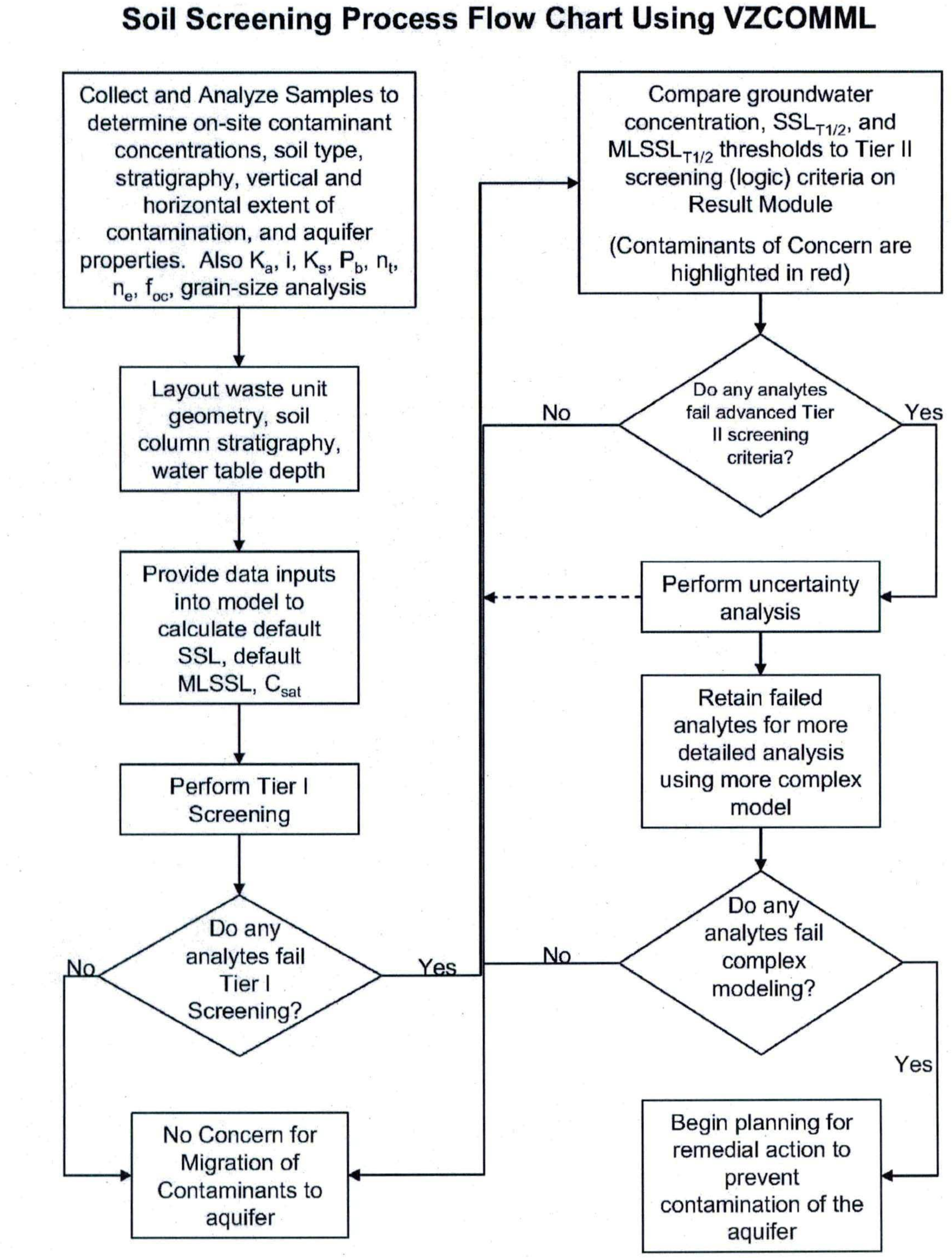

Figure 3-2. Flow Chart of Soil Screening Process (Rucker 2011)

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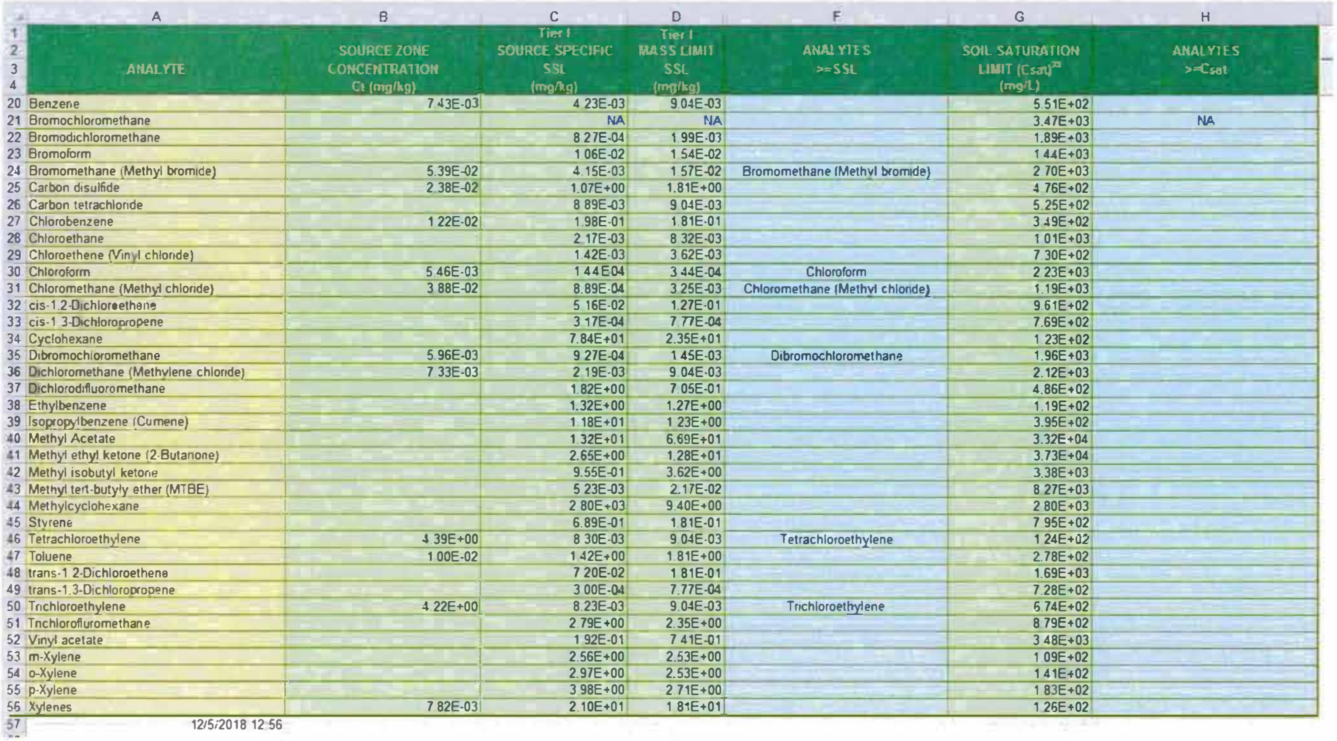

	A	B	C	D	F	G	H
1 2 3 4	ANALYTE	SOURCE ZONE CONCENTRATION Ct (mg/kg)	Tier I SOURCE SPECIFIC SSL (mg/kg)	Tier I MASS LIMIT SSL (mg/kg)	ANALYTES >=SSL	SOIL SATURATION LIMIT (Csat)[23] (mg/L)	ANALYTES >=Csat
20	Benzene	7.43E-03	4.23E-03	9.04E-03		5.51E+02	
21	Bromochloromethane		NA	NA		3.47E+03	NA
22	Bromodichloromethane		8.27E-04	1.99E-03		1.89E+03	
23	Bromoform		1.06E-02	1.54E-02		1.44E+03	
24	Bromomethane (Methyl bromide)	5.39E-02	4.15E-03	1.57E-02	Bromomethane (Methyl bromide)	2.70E+03	
25	Carbon disulfide	2.38E-02	1.07E+00	1.81E+00		4.76E+02	
26	Carbon tetrachloride		8.89E-03	9.04E-03		5.25E+02	
27	Chlorobenzene	1.22E-02	1.98E-01	1.81E-01		3.49E+02	
28	Chloroethane		2.17E-03	8.32E-03		1.01E+03	
29	Chloroethene (Vinyl chloride)		1.42E-03	3.62E-03		7.30E+02	
30	Chloroform	5.46E-03	1.44E-04	3.44E-04	Chloroform	2.23E+03	
31	Chloromethane (Methyl chloride)	3.88E-02	8.89E-04	3.25E-03	Chloromethane (Methyl chloride)	1.19E+03	
32	cis-1,2-Dichloroethene		5.16E-02	1.27E-01		9.61E+02	
33	cis-1,3-Dichloropropene		3.17E-04	7.77E-04		7.69E+02	
34	Cyclohexane		7.84E+01	2.35E+01		1.23E+02	
35	Dibromochloromethane	5.96E-03	9.27E-04	1.45E-03	Dibromochloromethane	1.96E+03	
36	Dichloromethane (Methylene chloride)	7.33E-03	2.19E-03	9.04E-03		2.12E+03	
37	Dichlorodifluoromethane		1.82E+00	7.05E-01		4.86E+02	
38	Ethylbenzene		1.32E+00	1.27E+00		1.19E+02	
39	Isopropylbenzene (Cumene)		1.18E+01	1.23E+00		3.95E+02	
40	Methyl Acetate		1.32E+01	6.69E+01		3.32E+04	
41	Methyl ethyl ketone (2-Butanone)		2.65E+00	1.28E+01		3.73E+04	
42	Methyl isobutyl ketone		9.55E-01	3.62E+00		3.38E+03	
43	Methyl tert-butyly ether (MTBE)		5.23E-03	2.17E-02		8.27E+03	
44	Methylcyclohexane		2.80E+03	9.40E+00		2.80E+03	
45	Styrene		6.89E-01	1.81E-01		7.95E+02	
46	Tetrachloroethylene	4.39E+00	8.30E-03	9.04E-03	Tetrachloroethylene	1.24E+02	
47	Toluene	1.00E-02	1.42E+00	1.81E+00		2.78E+02	
48	trans-1,2-Dichloroethene		7.20E-02	1.81E-01		1.69E+03	
49	trans-1,3-Dichloropropene		3.00E-04	7.77E-04		7.28E+02	
50	Trichloroethylene	4.22E+00	8.23E-03	9.04E-03	Trichloroethylene	6.74E+02	
51	Trichloroflurometthane		2.79E+00	2.35E+00		8.79E+02	
52	Vinyl acetate		1.92E-01	7.41E-01		3.48E+03	
53	m-Xylene		2.56E+00	2.53E+00		1.09E+02	
54	o-Xylene		2.97E+00	2.53E+00		1.41E+02	
55	p-Xylene		3.98E+00	2.71E+00		1.83E+02	
56	Xylenes	7.82E-03	2.10E+01	1.81E+01		1.26E+02	
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Figure 3-3 Results of Tier I Screening Using VZCOMML Model

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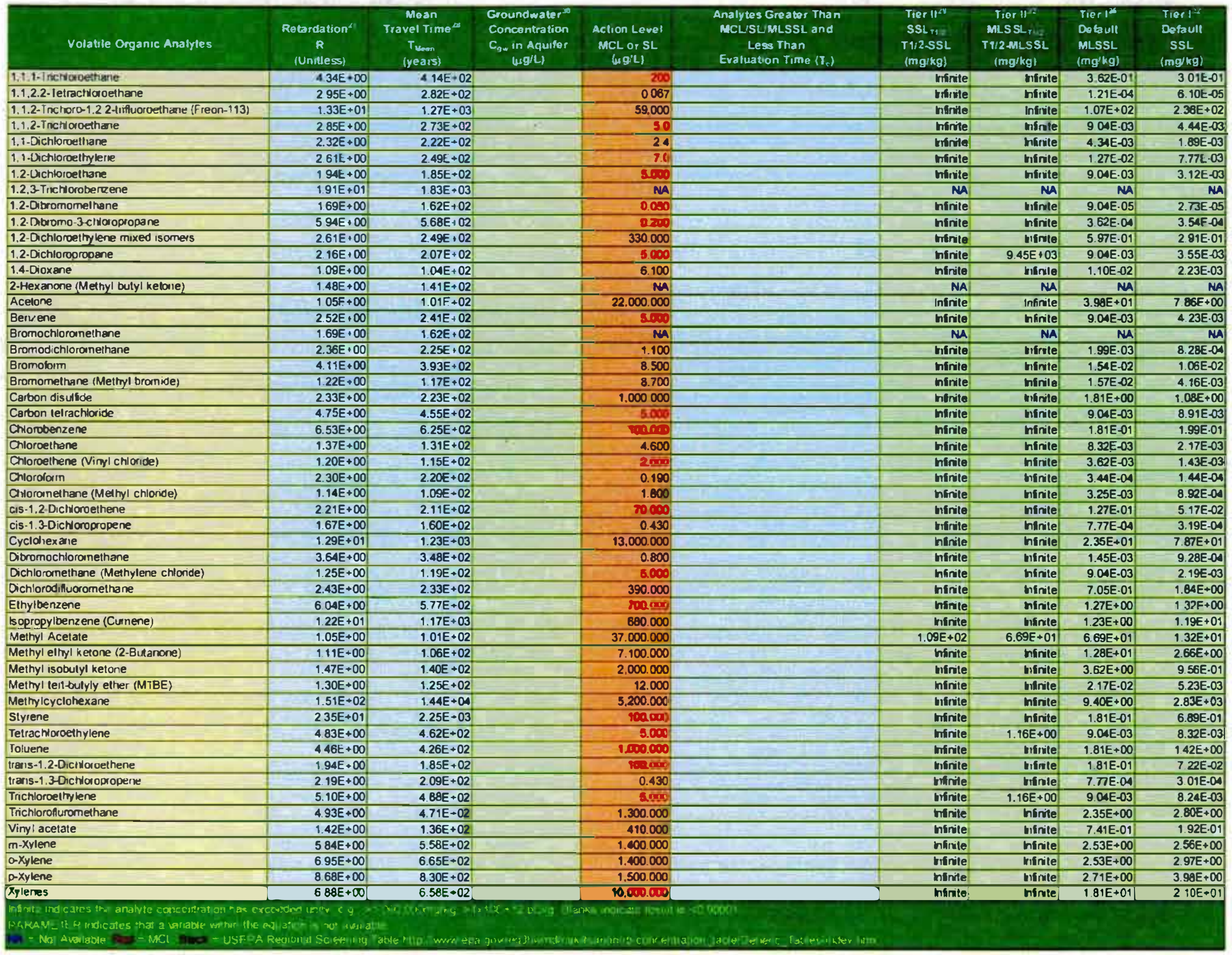

Volatile Organic Analytes	Retardation[41] R (Unitless)	Mean Travel Time[28] T_{Mean} (years)	Groundwater[30] Concentration C_{gw} in Aquifer (µg/L)	Action Level MCL or SL (µg/L)	Analytes Greater Than MCL/SL/MLSSL and Less Than Evaluation Time (T_c)	Tier II[29] $SSL_{T1/2}$ T1/2-SSL (mg/kg)	Tier II[32] $MLSSL_{T1/2}$ T1/2-MLSSL (mg/kg)	Tier I[26] Default MLSSL (mg/kg)	Tier I[32] Default SSL (mg/kg)
1,1,1-Trichloroethane	4.34E+00	4.14E+02		200		Infinite	Infinite	3.62E-01	3.01E-01
1,1,2,2-Tetrachloroethane	2.95E+00	2.82E+02		0.067		Infinite	Infinite	1.21E-04	6.10E-05
1,1,2-Trichoro-1,2,2-trifluoroethane (Freon-113)	1.33E+01	1.27E+03		59,000		Infinite	Infinite	1.07E+02	2.38E+02
1,1,2-Trichloroethane	2.85E+00	2.73E+02		5.0		Infinite	Infinite	9.04E-03	4.44E-03
1,1-Dichloroethane	2.32E+00	2.22E+02		2.4		Infinite	Infinite	4.34E-03	1.89E-03
1,1-Dichloroethylene	2.61E+00	2.49E+02		7.0		Infinite	Infinite	1.27E-02	7.77E-03
1,2-Dichloroethane	1.94E+00	1.85E+02		5.000		Infinite	Infinite	9.04E-03	3.12E-03
1,2,3-Trichlorobenzene	1.91E+01	1.83E+03		NA		NA	NA	NA	NA
1,2-Dibromomethane	1.69E+00	1.62E+02		0.050		Infinite	Infinite	9.04E-05	2.73E-05
1,2-Dibromo-3-chloropropane	5.94E+00	5.68E+02		0.200		Infinite	Infinite	3.62E-04	3.54E-04
1,2-Dichloroethylene mixed isomers	2.61E+00	2.49E+02		330.000		Infinite	Infinite	5.97E-01	2.91E-01
1,2-Dichloropropane	2.16E+00	2.07E+02		5.000		Infinite	9.45E+03	9.04E-03	3.55E-03
1,4-Dioxane	1.09E+00	1.04E+02		6.100		Infinite	Infinite	1.10E-02	2.23E-03
2-Hexanone (Methyl butyl ketone)	1.48E+00	1.41E+02		NA		NA	NA	NA	NA
Acetone	1.05E+00	1.01E+02		22,000.000		Infinite	Infinite	3.98E+01	7.86E+00
Benzene	2.52E+00	2.41E+02		5.000		Infinite	Infinite	9.04E-03	4.23E-03
Bromochloromethane	1.69E+00	1.62E+02		NA		NA	NA	NA	NA
Bromodichloromethane	2.36E+00	2.25E+02		1.100		Infinite	Infinite	1.99E-03	8.28E-04
Bromoform	4.11E+00	3.93E+02		8.500		Infinite	Infinite	1.54E-02	1.06E-02
Bromomethane (Methyl bromide)	1.22E+00	1.17E+02		8.700		Infinite	Infinite	1.57E-02	4.16E-03
Carbon disulfide	2.33E+00	2.23E+02		1,000.000		Infinite	Infinite	1.81E+00	1.08E+00
Carbon tetrachloride	4.75E+00	4.55E+02		5.000		Infinite	Infinite	9.04E-03	8.91E-03
Chlorobenzene	6.53E+00	6.25E+02		100.000		Infinite	Infinite	1.81E-01	1.99E-01
Chloroethane	1.37E+00	1.31E+02		4.600		Infinite	Infinite	8.32E-03	2.17E-03
Chloroethene (Vinyl chloride)	1.20E+00	1.15E+02		2.000		Infinite	Infinite	3.62E-03	1.43E-03
Chloroform	2.30E+00	2.20E+02		0.190		Infinite	Infinite	3.44E-04	1.44E-04
Chloromethane (Methyl chloride)	1.14E+00	1.09E+02		1.800		Infinite	Infinite	3.25E-03	8.92E-04
cis-1,2-Dichloroethene	2.21E+00	2.11E+02		70.000		Infinite	Infinite	1.27E-01	5.17E-02
cis-1,3-Dichloropropene	1.67E+00	1.60E+02		0.430		Infinite	Infinite	7.77E-04	3.19E-04
Cyclohexane	1.29E+01	1.23E+03		13,000.000		Infinite	Infinite	2.35E+01	7.87E+01
Dibromochloromethane	3.64E+00	3.48E+02		0.800		Infinite	Infinite	1.45E-03	9.28E-04
Dichloromethane (Methylene chloride)	1.25E+00	1.19E+02		5.000		Infinite	Infinite	9.04E-03	2.19E-03
Dichlorodifluoromethane	2.43E+00	2.33E+02		390.000		Infinite	Infinite	7.05E-01	1.84E+00
Ethylbenzene	6.04E+00	5.77E+02		700.000		Infinite	Infinite	1.27E+00	1.32E+00
Isopropylbenzene (Cumene)	1.22E+01	1.17E+03		680.000		Infinite	Infinite	1.23E+00	1.19E+01
Methyl Acetate	1.05E+00	1.01E+02		37,000.000		1.09E+02	6.69E+01	6.69E+01	1.32E+01
Methyl ethyl ketone (2-Butanone)	1.11E+00	1.06E+02		7,100.000		Infinite	Infinite	1.28E+01	2.66E+00
Methyl isobutyl ketone	1.47E+00	1.40E+02		2,000.000		Infinite	Infinite	3.62E+00	9.56E-01
Methyl tert-butyly ether (MTBE)	1.30E+00	1.25E+02		12.000		Infinite	Infinite	2.17E-02	5.23E-03
Methylcyclohexane	1.51E+02	1.44E+04		5,200.000		Infinite	Infinite	9.40E+00	2.83E+03
Styrene	2.35E+01	2.25E+03		100.000		Infinite	Infinite	1.81E-01	6.89E-01
Tetrachloroethylene	4.83E+00	4.62E+02		5.000		Infinite	1.16E+00	9.04E-03	8.32E-03
Toluene	4.46E+00	4.26E+02		1,000.000		Infinite	Infinite	1.81E+00	1.42E+00
trans-1,2-Dichloroethene	1.94E+00	1.85E+02		100.000		Infinite	Infinite	1.81E-01	7.22E-02
trans-1,3-Dichloropropene	2.19E+00	2.09E+02		0.430		Infinite	Infinite	7.77E-04	3.01E-04
Trichloroethylene	5.10E+00	4.88E+02		5.000		Infinite	1.16E+00	9.04E-03	8.24E-03
Trichlorofluromethane	4.93E+00	4.71E+02		1,300.000		Infinite	Infinite	2.35E+00	2.80E+00
Vinyl acetate	1.42E+00	1.36E+02		410.000		Infinite	Infinite	7.41E-01	1.92E-01
m-Xylene	5.84E+00	5.58E+02		1,400.000		Infinite	Infinite	2.53E+00	2.56E+00
o-Xylene	6.95E+00	6.65E+02		1,400.000		Infinite	Infinite	2.53E+00	2.97E+00
p-Xylene	8.68E+00	8.30E+02		1,500.000		Infinite	Infinite	2.71E+00	3.98E+00
Xylenes	6.88E+00	6.58E+02		10,000.000		Infinite	Infinite	1.81E+01	2.10E+01

Infinite indicates the analyte concentration has exceeded unity, e.g. [illegible]. Blanks indicate result is <0.00001

PARAMETER indicates that a variable within the equation is not available

NA = Not Available Red = MCL Black = USEPA Regional Screening Table http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/Generic_Tables/index.htm

Figure 3-4 Results of Tier II Screening Using VZCOMML Model

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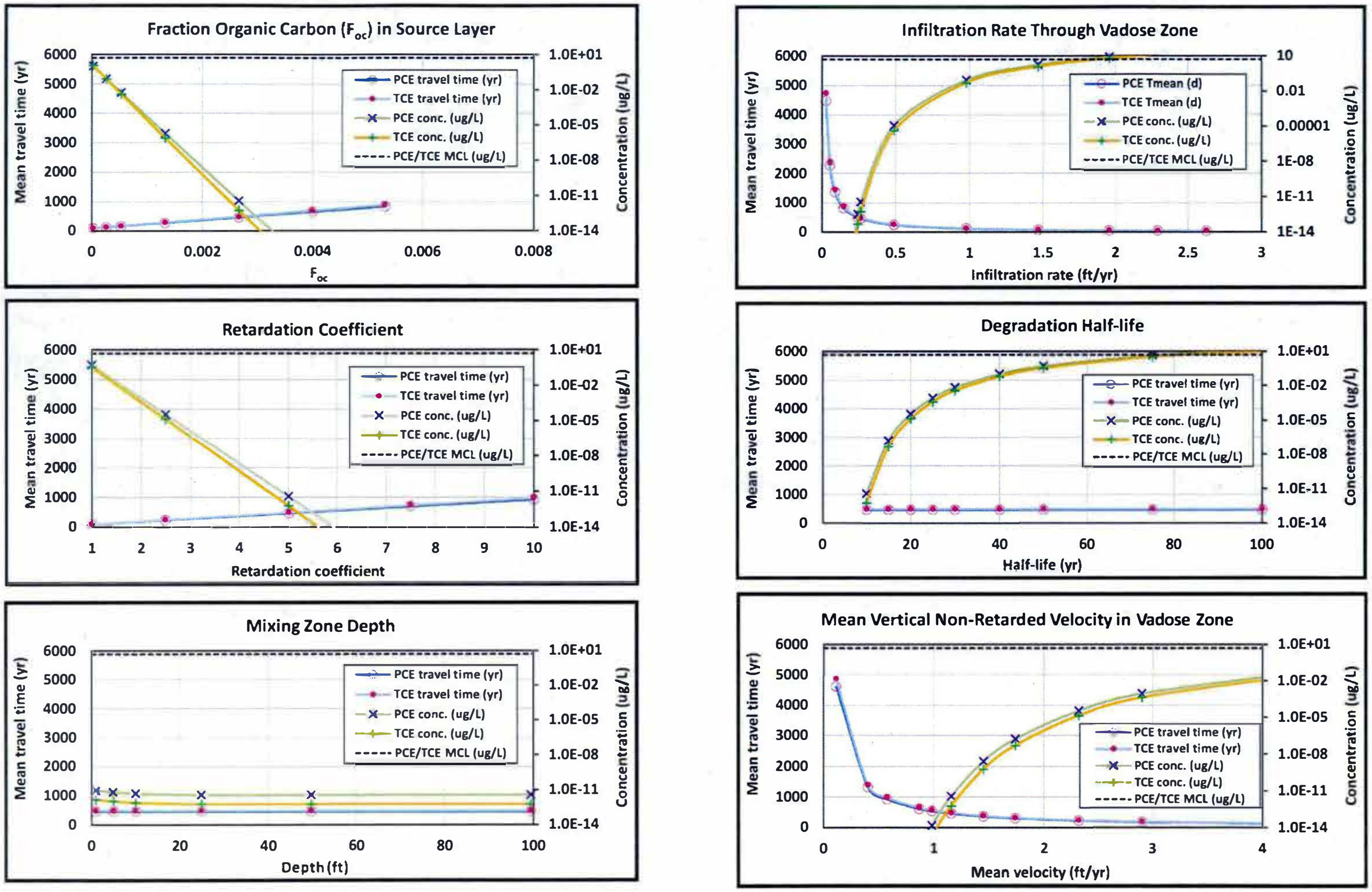

Figure 3-5 Sensitivity Analyses for Key Model Input Parameters (A)

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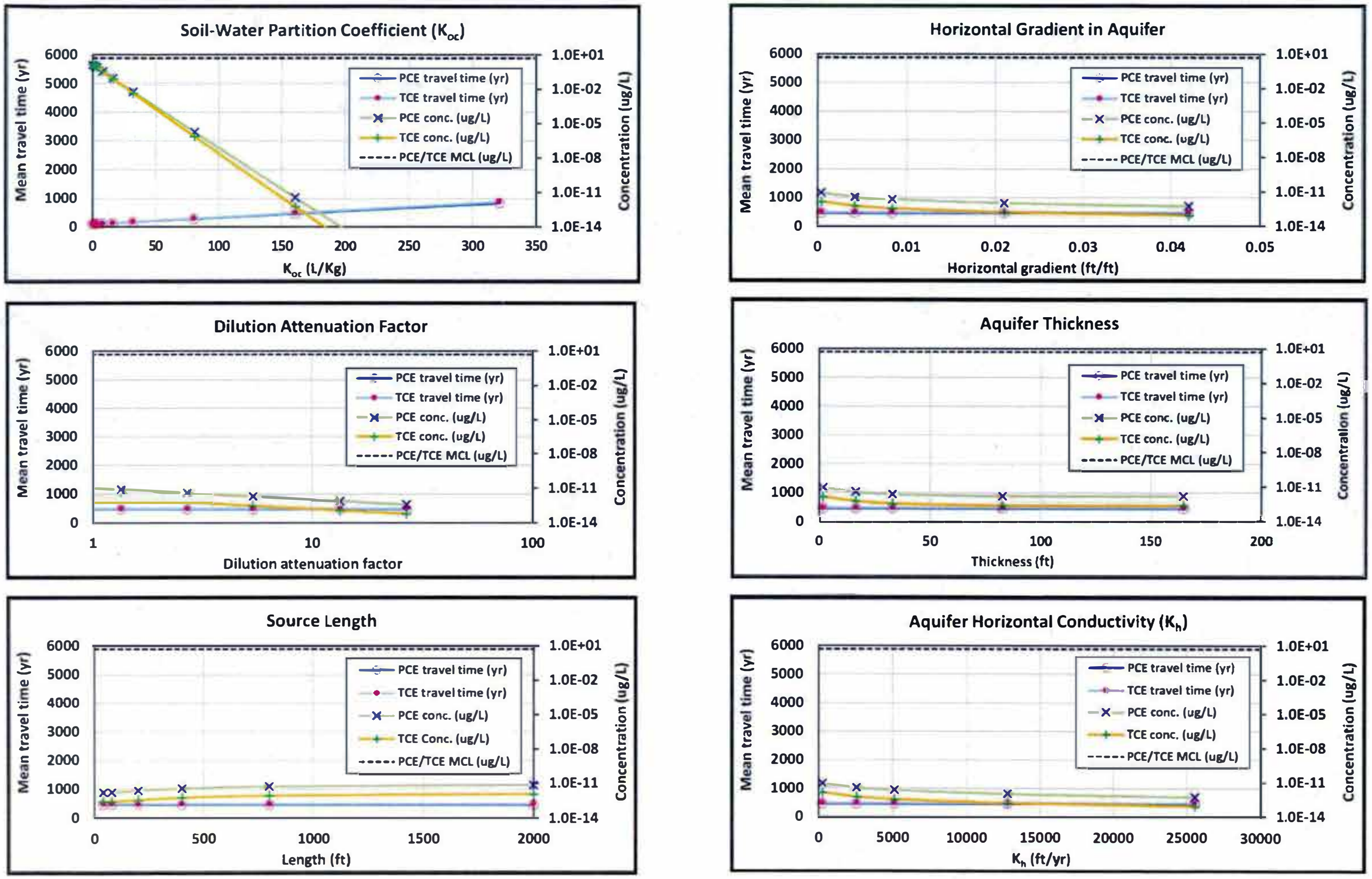

Figure 3-6 Sensitivity Analyses for Key Model Input Parameters (B)

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4.0 SUMMARY AND CONCLUSIONS

The study consisted of an update to the HCM, performance of two levels of screening to identify COCs, an update to the mathematical model using VZCOMML, performance of predictive simulations to determine exposure times and concentrations for the constituents of concern, and performance of sensitivity simulations to assess the effects of parameter, boundary condition, or conceptualization uncertainty on the predicted results. The primary changes to the HCM included: 1) a more detailed representation of localized stratigraphy, 2) the need to evaluate only the Trenches Area, because the other two areas have been successfully remediated, and 3) new source term concentrations that are based on recent soil sampling in July 2018. A Tier I and II Soil Screening process identified TCE and PCE as primary constituents of concern for the updated model. A VZCOMML model was constructed based on available site-specific data and a reasonably conservative modeling approach.

Results of the VZCOMML predictive modeling indicated that PCE and TCE would be below Maximum Concentration Limits (MCLs) at the downgradient receptor, which is a monitoring well located at the edge of the waste unit. Maximum predicted concentrations for PCE and TCE over the 1,000-year evaluation period are 12 to 13 orders of magnitude below MCLs at the receptor due to the large unsaturated zone transport distance (depth), comparatively low rates of flow, and first-order organic decay operating over long transport times. Sensitivity analysis indicated that the predicted results are sensitive to fractional organic carbon, infiltration rate, retardation, and degradation rate. The least sensitive parameters include aquifer thickness, source length, and aquifer hydraulic conductivity.

The updated model indicates that TCE and PCE at the ARP OU Trenches Area no longer pose a threat to human health and the environment. Three primary factors have changed since the original modeling was performed nearly 20 years ago that lead to this result. First, active and passive SVE have removed mass and reduced concentrations in the vadose zone. Second, the modeling performed includes a greater level of discretization (five layers instead of two) and incorporates site specific data that account for thin layers of low hydraulic conductivity material. The greater level of numerical detail and stratigraphic consideration results in longer travel times and increase attenuation of constituents. Third, recent site data indicate that the water table occurs at a greater depth of approximately 123.5 ft, which results in a larger thickness and longer travel times within the unsaturated zone. This provides additional protection for groundwater because of the increased time for natural attenuation of COCs to occur prior to reaching the water table.

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