
Hydrocarbon Risk Calculator User Manual

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Preface

The “Statement of Cooperation” working group is pleased to present this released and approved draft version of the user manual for the Alaska Hydrocarbon Risk Calculator. This manual does not constitute Alaska Department of Environmental Conservation (ADEC) guidance, policy, or rule making. The ADEC is releasing the calculator as an alternative Method 3 calculator under Title 18, Section 75.340(e)(2), of the *Alaska Administrative Code* (AAC) that may be proposed for use on sites with petroleum hydrocarbon contamination. The ADEC may take action at variance with this document, and the results shown may not in every circumstance be accepted or approved for site management decisions. The user manual and excel calculator tool should be proposed and approved for use in a work plan submitted under 18 AAC 75 before performance of the work needed to develop information required by this tool.

This user manual and the associated excel calculator tool were created under the Alaska Statement of Cooperation (SOC), which is an agreement among the ADEC; U.S. Environmental Protection Agency; Departments of the Army, Air Force, Navy, Military and Veterans Affairs (Army National Guard), and Interior; Federal Aviation Administration; and U.S. Coast Guard. The objective of the agreement is to work cooperatively to identify and resolve issues affecting human health and the environment through promoting compliance with environmental laws, preventing pollution, creating partnerships to identify and clean up contaminants and pollution, promoting training, and coordinating with affected Tribes. A subcommittee or “working group” was formed under the SOC to evaluate the characterization and fate and transport of petroleum hydrocarbons spilled in the environment and the risks posed by petroleum contamination.

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Acronyms and Abbreviations

AAC	<i>Alaska Administrative Code</i>
ADEC	Alaska Department of Environmental Conservation
ASTM	American Society for Testing and Materials
BTEX	benzene, toluene, ethylbenzene, and xylene
C_{sat}	soil saturation concentration
DAF	dilution-attenuation factor
DRO	diesel-range organic
EPA	U. S. Environmental Protection Agency
EPH	extractable petroleum hydrocarbon
HRC	hydrocarbon risk calculator
g/cm^3	grams per cubic centimeters
GRO	gasoline-range organic
k_d	soil-water partitioning coefficient
kg/L	kilograms per liter
K_{oc}	organic carbon partitioning coefficient
lb/ft^3	pounds per cubic feet
MCL	maximum contaminant level
mg/cm^3	milligrams per cubic centimeter
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
$\mu\text{g}/\text{L}$	micrograms per liter
NAPL	nonaqueous phase liquid
PAH	polycyclic aromatic hydrocarbons
PID	photoionization detector
ppm	parts per million
RRO	residual-range organic

SOC	Statement of Cooperation
TPH	total petroleum hydrocarbon
UCL	upper confidence limit
VPH	volatile petroleum hydrocarbon

SECTION 1

Introduction

The “hydrocarbon risk calculator” has been developed to assess the human health risks associated with petroleum hydrocarbon-contaminated sites. The hydrocarbon risk calculator (HRC) is a Microsoft Excel™ spreadsheet model and may be downloaded for free from the Alaska Department of Environmental Conservation (ADEC) web site (<http://dec.alaska.gov/spar/guidance.htm#csp>).

The hydrocarbon risk calculator is specifically designed to address fuel hydrocarbon spill sites and includes a library of sparingly soluble (immiscible) organic compounds which may be present as constituents of a multi-constituent hydrocarbon release. The site characterization and risk calculation approach described in this manual is geared toward characterizing the nature, extent, and risk posed by discrete, contiguous, nonaqueous phase liquid (NAPL) source areas (and not toward the statistical characterization of a large area or industrial zone containing multiple sources). This discrete contiguous source area approach is likely conservative compared to an area-wide risk assessment. The hydrocarbon risk calculator follows ADEC Method 3 guidelines and, where appropriate, may also be used in ADEC Method 4 calculations. Users of the hydrocarbon risk calculator must follow applicable ADEC regulations and guidance documents including, but not limited to, the following: Title 18, Chapter 75, of the *Alaska Administrative Code* (18 AAC 75); 18 AAC 78; Cleanup Levels Guidance (ADEC, 2008); Cumulative Risk Guidance (ADEC, 2008); Risk Assessment Procedures Manual (ADEC, 2010); Guidance For Data Reporting, Data Reduction, and Treatment of Non-Detect Values (ADEC, 2008); Draft Vapor Intrusion Guidance for Contaminated Sites (ADEC, 2009); Guidelines for Total Organic Carbon (TOC) Sample Collection and Data Reduction for Method Three and Method Four (ADEC, 2008); and Draft Field Sampling Guidance (ADEC, 2010).

Features of the hydrocarbon risk calculator are as follows:

- The hydrocarbon risk calculator performs a forward calculation of carcinogenic and non-carcinogenic human health risk for the following exposure routes:
 - Soil direct contact (ingestion and dermal adsorption),
 - Migration to outdoor air,
 - Vapor intrusion or migration to indoor air,
 - Migration to groundwater, and
 - Groundwater ingestion.
- The calculator may be used iteratively to estimate risk-based alternative cleanup levels.
- The human health risk calculations follow standard U.S. Environmental Protection Agency (EPA) and ADEC risk calculation approaches (ADEC, 2010, 2008a, 2008b, 2008c; EPA, 1996, 1989).
- Most variables in the EPA and ADEC risk calculation equations may be adjusted to match the conditions at the subject site.

- The calculator uses both an indicator compound approach, in which the risks presented by individual compounds are calculated for each pathway; and a surrogate compound approach, in which the risks presented by aromatic and aliphatic, equivalent-carbon fractions are calculated for each pathway.
- The HRC can simultaneously calculate cumulative risk for 34 individual compounds. Individual compounds include benzene, toluene, ethylbenzene, and xylene (BTEX); the 16 polycyclic aromatic hydrocarbon (PAH) compounds (which are listed as indicator compounds by the ADEC [2008c]; and 7 additional non-carcinogens and 7 additional carcinogens (drawn from the list of sparingly soluble organic compounds in Tables B1 or C of 18 AAC 75 (2008a)).
- Twelve aromatic and aliphatic, equivalent-carbon fractions are included in the phase-partitioning calculations, and risks for each exposure pathway are calculated for gasoline-range organic (GRO) aromatics and aliphatics, diesel-range organic (DRO) aromatics and aliphatics, and residual-range organic (RRO) aromatics and aliphatics.
- The calculator presents a “potential cumulative risk calculation” assuming that all exposure pathways are complete and a “current cumulative risk calculation” for the pathways complete at the present time. The cumulative carcinogenic and cumulative non-carcinogenic risks are calculated for the individual compounds (following ADEC guidance documents); the risk associated with GRO, DRO, and RRO aromatics and aliphatics are not included in the cumulative risk calculations.
- The basic risk calculations are performed for residential and industrial scenarios. A trench worker scenario and a user specified “site visitor” scenario are provided as options.
- The calculator applies either three-phase or four-phase partitioning equations depending on whether NAPL is present. Where NAPL is present, four-phase partitioning and Raoult’s Law are used to calculate the vapor pressure and effective solubility of the hydrocarbon constituents. The four-phase partitioning solution is calculated by using the Excel Solver add-in tool following the method of San Juan and Park (2000).
- The calculator uses the Johnson and Ettinger model as implemented by the EPA (Environmental Quality Management, Inc., 2004) to characterize risk associated with the vapor intrusion (migration-to-indoor-air) route. Risks associated with the vapor intrusion pathway may be calculated from measured soil, groundwater, or vapor concentrations.
- The calculator uses a dilution-attenuation factor (DAF) that accounts for the presence of contaminated soil in either the vadose zone or saturated zone and adjusts the migration-to-groundwater risks accordingly.
- The calculator assesses whether the subject site meets the human health risk and migration-to-groundwater closeout criteria contained in the ADEC regulations, 18 AAC 75, and provides a characterization of limitations on the placement of soil excavated and transported from the subject site.

The following are primary differences between the ADEC Method 3 online risk calculator and the hydrocarbon risk calculator:

- The hydrocarbon risk calculator applies either three-phase or four-phase partitioning equations, whichever is appropriate for the specific situation, whereas the ADEC online calculator only performs three-phase calculations and does not recognize solubility and vapor pressure limits.
- The hydrocarbon risk calculator incorporates the Johnson and Ettinger vapor intrusion model, while the ADEC online calculator does not assess risk associated with the vapor intrusion pathway.
- The hydrocarbon risk calculator calculates the risk posed by the GRO, DRO and RRO aromatic and aliphatic groups rather than presenting a hydrocarbon alternative cleanup level (an approach that allows the responsible party and ADEC to assess whether the site meets the risk criteria stipulated in 18 AAC 75).
- The hydrocarbon risk calculator accounts for saturated zone sources, whereas the ADEC online calculator assumes that the source is in the vadose zone only.

The hydrocarbon risk calculator is presented here as a peer-reviewed model, approved by the ADEC as an alternative to the ADEC online Method 3 calculator. The peer reviews were performed by David Barnes of the University of Alaska Fairbanks, School of Engineering (in 2006, 2009 and 2010), and SLR International Corp (in 2008 and 2010).

The hydrocarbon risk calculator was originally developed by Lawrence Acomb of Geosphere, Inc. (in 2001) and was refined by three ADEC and Statement of Cooperation (SOC) working groups. This user manual was developed by Geosphere, initially working under subcontract to CH2M HILL (under contract to the Federal Aviation Administration); and later working under subcontract to AECOM (under contract to the Air Force Center for Environmental Excellence). The user manual was edited by SLR and the University of Alaska Fairbanks, working under contract to ADEC, and by three ADEC working groups. In addition to the hydrocarbon risk calculator, eight technical background documents (available on the ADEC web site) provide information on the hydrocarbon risk calculator concepts discussed in this document.

1.1 Objective of User Manual

The objective of this hydrocarbon risk calculator user manual is to provide enough information about the calculator to allow environmental professionals to be able to start using the calculator. Users of the hydrocarbon risk calculator are encouraged to become more familiar with the concepts introduced in this document by reading the eight SOC technical papers, reading journal articles, attending conferences, and taking professional short courses.

1.2 Organization of User Manual

This user manual is organized as follows:

- Section 1 provides an introduction to the hydrocarbon risk calculator, which identifies some primary features of the calculator.
- Section 2 provides background information on hydrocarbon phase partitioning and the basic site conceptual model employed in the hydrocarbon risk calculator.

- Section 3 describes the general layout of the hydrocarbon risk calculator.
- Section 4 describes input to the calculator. The discussion of the input parameters provides information on suggested sources of the input values.
- Section 5 describes the output of the calculator.
- Appendix A provides information on the suggested presentation of site characterization data, including templates for summarizing soil and groundwater concentration data and extractable petroleum hydrocarbon (EPH) and volatile petroleum hydrocarbon (VPH) data for input to the HRC.
- Appendix B provides information on the dilution-attenuation calculations.
- Appendix C describes selected calculations performed by the calculator.

1.3 Hardware and Software Requirements

The hydrocarbon risk calculator is a Microsoft Excel XP or Excel 2003 spreadsheet. When using Excel 2007 or 2010 it is recommended that users save the spreadsheet as an Excel 2003 spreadsheet so that the spreadsheet is compatible with Excel 2003 (Excel 2007 and 2010 save spreadsheets with macros in a file format not compatible with Excel 2003). A “minimum system requirement” has not been determined, but the spreadsheet has been operated without difficulty on a Windows Millennium Edition operating system (Microsoft, 1999) with 256 kilobytes of random-access memory (RAM). The Excel workbook containing the hydrocarbon risk calculator, as downloaded from the ADEC web site, is about 1,500 kilobytes. It is recommended that, after downloading the Excel workbook, each application of the hydrocarbon risk calculator be saved as a separate file using the “Save as” option.

The hydrocarbon risk calculator uses both a “Macro” and the Excel “Solver” and “Goal Seek” add-in tools. When opening the hydrocarbon risk calculator workbook in Excel 2003, users will commonly be prompted to either “Enable Macros” or “Disable Macros.” To perform new calculations, the user must click on the “Enable Macros” option when opening the spreadsheet. If the user does not get the prompt to “Enable Macros” and the calculate button does not function, then the security setting on the computer may need to be set to a lower level (in Excel, click on Tools, then on Macro, then on Security, then select the medium security setting). When opening the hydrocarbon risk calculator workbook in Excel 2007 and 2010 the macro will typically be disabled and the user will have to “enable this content” by clicking the option box in the security warning highlight bar.

The hydrocarbon risk calculator requires that the Excel Solver add-in tool is available. The user can determine whether the Solver tool is available in Excel 2003 by opening Excel, clicking on “Tools” and then on “Add-ins” in the drop-down menu. If there is a check in the box next to “Solver Add-in” then the solver tool is available, if there is not a check in the box next to “Solver Add-in” (but the Solver Add-in tool is listed), then check or click on the box to activate Solver. If the “Solver Add-in” tool is not listed in the Add-in drop down menu, then Solver may need to be loaded from the Excel program discs. In Excel 2007 and 2010 the user can determine whether the Solver tool is available by opening Excel, clicking on “Data” tab and then looking for Solver in the “Analysis” block on the far right side of the “Data” tool bar. If solver is not available in

Excel 2007 or 2010 then click on the “Office Button” in the upper left corner, click on Excel options in the drop down menu, click on “Add-ins” in the next drop-down menu, click on “Manage Add-ins” and the “Go” button in the next menu, and finally click in the box next to “Solver Add-in” in the Add-ins available list.

Finally, a few users have reported that the hydrocarbon risk calculator macro could not find the Solver add-in feature. To rectify this issue, try the following steps: open “Hydrocarbon Risk Calculator”; click Tools, then Macro, then Visual Basic Editor. This action will automatically open an editor for the macros and coding that are specific to “Hydrocarbon Risk Calculator.” Within Visual Basic Editor, click Tools, then References. If there is a checked box next to “MISSING:SOLVER.XLA,” do the following: click browse; browse to the Microsoft function Library folder for Solver, make sure the file browser will view *.xla files, and click “SOLVER.XLA.” An example system path for Excel 2003 is “C:\Program Files\Microsoft Office\OFFICE11\Library\SOLVER\SOLVER.XLA.” Then save the Visual Basic Editor file, close Visual Basic Editor file, save the hydrocarbon risk calculator, close the hydrocarbon risk calculator, and re-open hydrocarbon risk calculator.

SECTION 2

Risk Calculator Background–Phase Partitioning and Site Conceptual Model

This section briefly describes hydrocarbon phase partitioning and the site conceptual model used in the hydrocarbon risk calculator.

2.1 Phase Partitioning

Understanding the human health and environmental risks associated with spilled fuel hydrocarbons requires an understanding and quantification of the phase distribution, phase changes, and transport of the hydrocarbon in the environment. Individual petroleum hydrocarbon compounds may exist at a contaminated site in four phases:

- As hydrocarbon molecules in air-filled soil pores (the vapor phase)
- As hydrocarbon molecules in soil moisture and groundwater (the dissolved phase)
- As hydrocarbon molecules bound to the soil matrix (the adsorbed phase)
- As hydrocarbon molecules surrounded predominately by other hydrocarbon molecules (the oil phase or NAPL)

The partitioning of a hydrocarbon constituent among these four phases is dependent on the properties and concentrations of the hydrocarbon compounds present, and on the properties of the soil. In this manual, the terms “oil phase,” “oil,” “free product,” “free phase” and “NAPL” are used synonymously. The terms “oil,” “free product” and “NAPL” as used in this manual do not indicate that the oil phase is mobile. Indeed, most of the free product in the soil at a contaminated site is generally held in the soil pores by capillary forces as immobile, residual saturation, and even the oil that collects on the water table surface in monitoring wells often is not mobile in the soil environment at the scale of the NAPL source area (i.e., the oil will not migrate downgradient into previously uncontaminated soils, hence, the NAPL source area will not expand).

Hydrocarbon phase partitioning describes the movement and redistribution of hydrocarbon molecules between the dissolved, vapor, adsorbed, and nonaqueous liquid phases. The movement of molecules between the phases occurs continuously in the soil environment because of the thermal energy of the molecules. Phase equilibrium exists when the movement into each phase equals the rate of movement out of the phase. The hydrocarbon concentrations in each phase at equilibrium are defined by the phase partitioning relationships. The following key terms which are required to understand phase partitioning are discussed below:

- Solubility
- Vapor Pressure and concentration

- Sorbed concentration
- Soil saturation concentration
- Raoult's Law

Chemical specific parameters such as solubility, vapor pressure, Henry's Constants, and diffusion coefficients are provided in the calculator. The data included in the calculator have been obtained from numerous references, including the following:

- ADEC *Cleanup Levels Guidance* (2008) at <http://www.dec.state.ak.us/SPAR/csp/guidance/cleanuplevels.pdf>
- Oak Ridge National Laboratory Risk Assessment Information System online database (2010) at http://rais.ornl.gov/cgi-bin/tools/TOX_search?select=chem
- EPA fact sheet, "Correcting the Henry's Law Constant for Soil Temperature" (2001), at <http://www.epa.gov/athens/learn2model/part-two/onsite/doc/factsheet.pdf>
- Total Petroleum Hydrocarbon Criteria Working Group, Volume 3, *Selection of Representative TPH Fractions Based on Fate and Transport Considerations* (1997)

2.1.1 Solubility

The solubility of a compound (S) describes the maximum concentration of the compound that may be dissolved in water. If a given hydrocarbon compound is mixed with water at concentrations above its solubility limit, the compound will dissolve in the water to its solubility limit and the remainder of the compound will be present as free product. The solubility of hydrocarbons in water varies as a function of temperature and total dissolved solids (however, the effect of temperature is relatively small within the range of groundwater temperatures). Solubility values for common fuel hydrocarbons range over many orders of magnitude; for example, the solubility of benzene is about 1,750 milligrams per liter (mg/L), and the solubility of hexadecane (C16 aliphatic) is about 0.00005 mg/L.

Table 1 lists solubilities for BTEX and for aromatics and aliphatics with equivalent carbon numbers representative of Alaskan fuels (the aromatic and aliphatic, equivalent-carbon solubilities were calculated from the regression equations developed by the Total Petroleum Hydrocarbon Criteria Working Group [1997]). (Tables and figures are included following the manual text.)

2.1.2 Vapor Pressure and Concentration

Similar to the concept of solubility, each hydrocarbon compound has a vapor pressure that describes the maximum quantity of the compound that may volatilize in the air. If a given hydrocarbon compound is mixed with air at concentrations above its vapor pressure limit, the compound will volatilize into the air to its vapor pressure limit and the remainder of the compound will be present as free product. The concentration in the vapor phase may be calculated from the ideal gas law as follows:

$$\text{Vapor concentration (mg/L)} = (1000 * \text{vapor pressure} * \text{molecular weight} * \text{volume}) / (n * R * T)$$

Where: n = moles of compound

R = universal gas constant = 0.082 Liter * atm/°K * mole

T = temperature in degrees Kelvin

When water, air, and a hydrocarbon compound are present together, the concentration of the compound in the vapor phase may be related to the dissolved or aqueous concentration by the dimensionless Henry's constant (H') of the hydrocarbon compounds.

dimensionless Henry's constant (H') = vapor concentration (mg/L) / dissolved concentration (mg/L)

vapor concentration (mg/L) = dissolved concentration (mg/L) * dimensionless Henry's constant

The dimensionless Henry's constant (H') may be calculated from the Henry's constant (H), which has units of "atmosphere * meter³ / mole" as follows:

dimensionless Henry's constant (H') = $H / R * T$

Vapor pressure data and Henry's constants may be obtained from numerous references, such as the ADEC *Cleanup Levels Guidance* (2008b); chemical engineering handbooks; and EPA documents. Henry's constants for selected fuel hydrocarbons are listed in Table 1.

2.1.3 Sorbed Concentration

The concentration of the compound that is sorbed to the organic soil solids may be related to the dissolved concentration by the soil-water partitioning coefficient (k_d). The soil-water partitioning coefficient is a function of the organic carbon partitioning coefficient (K_{oc}) of the compounds and the fraction of organic carbon (f_{oc}) in the soil as follows:

Sorbed Concentration = dissolved concentration * K_d

Where: $K_d = K_{oc} * f_{oc}$ = soil-water partitioning coefficient (liter per kilogram [L/kg])

K_{oc} = organic carbon partitioning coefficient (L/kg)

f_{oc} = fraction of organic carbon (gram of carbon/gram of soil)

Note that the K_{oc} is a property of the hydrocarbon compound and K_d is a property of the compound in a specific soil environment. K_{oc} values may be obtained from numerous references, such as the ADEC *Cleanup Levels Guidance* (2008b); chemical engineering handbooks; and EPA documents. K_{oc} values for selected fuel hydrocarbons are listed in Table 1.

2.1.4 Soil Saturation Concentration

The ability of a soil to hold dissolved, vapor, and sorbed hydrocarbon is finite, and the maximum holding capacity of the soil for dissolved-, vapor-, and sorbed-phase hydrocarbons is described as the soil saturation concentration, which is abbreviated as C_{sat} . The C_{sat} of a compound may be calculated as follows:

$$C_{sat} = (S * n_w / \rho_b) + (S * H' * n_a / \rho_b) + (f_{oc} * k_{oc} * S)$$

Which reduces to:

$$C_{\text{sat}} \text{ (milligrams per kilogram [mg/kg])} = S / \rho_b * (K_d * \rho_b + n_w + H' * n_a)$$

Where: S = compound solubility in water (mg/L)

ρ_b = soil dry bulk density (kilograms per liter [kg/L] or milligrams per cubic centimeter [mg/cm³])

K_d = soil-water partitioning coefficient (L/kg)

n_w = water-filled porosity (L water/L soil)

H' = dimensionless Henry's Constant

n_a = air-filled porosity (L air/L soil)

At hydrocarbon concentrations below the saturation concentration (C_{sat}), all hydrocarbon present in the soil is distributed between the dissolved, vapor, and sorbed phases and the distribution of hydrocarbon may be referred to as a three-phase problem (Figure 1). At hydrocarbon concentrations above the saturation concentration, nonaqueous-phase hydrocarbon is present in addition to the dissolved, vapor, and sorbed phases, and the distribution of hydrocarbon may be referred to as a four-phase problem (Figure 2). On the left side of Figures 1 and 2, the soil particles are represented by the brown irregular-shaped grains, water is present as a thin layer covering the soil particles and as thick wedges or rings where the soil particles are in contact, and soil gas is present in the larger pore bodies. Hydrocarbon is represented by the red dots and red films. The diagrams on the right side of Figures 1 and 2 provide the same information, but the soil particles, water, and soil gas are shown as a contiguous block.

The understanding of three- and four-phase partitioning and having a quantifiable boundary between three- and four- phase distributions is important when assessing fate and transport and risk for the following reasons:

- Below C_{sat} , the risk associated with the migration-to-outdoor-air, migration-to-indoor-air, and migration-to-groundwater pathways increases linearly with increasing bulk soil concentration.
- At concentrations above C_{sat} , the risk associated with the vapor-inhalation and migration-to-groundwater pathways does not increase linearly, but rather remains relatively constant because the vapor and dissolved concentrations do not change as the mass of free product in the system increases (Figures 3 and 4). See further discussion of C_{sat} , below.

In Figure 3 the “bulk soil concentration” is the sum of the concentrations in the dissolved, vapor, adsorbed, and nonaqueous phases. The bulk soil concentration is the value provided by the EPA 8021, EPA 8260, EPA 8270, AK101, AK102, and AK103 test methods.

The C_{sat} values for several fuel hydrocarbon compounds and fractions are shown in Table 1 for a soil with the ADEC default soil properties. Note that the C_{sat} values for diesel-range aliphatics are relatively low (<10 mg/kg, given the default organic carbon content assumption), indicating that NAPL is present at most DRO-contaminated sites and that four-phase partitioning is

necessary to characterize the phase distribution of hydrocarbon constituents at these sites. Typical soils hold less than about 10 to 50 mg/kg of spilled diesel fuel in the vapor, dissolved, and adsorbed phases. Hydrocarbon present in the soil above the soil saturation concentration is present as NAPL (synonymous with free product). At large spill sites, the majority of the spilled fuel is present as free product or NAPL (but most or all of the free product or NAPL is held in the soil by capillary forces, is typically not mobile at the scale of the NAPL source area, and often does not appear in monitoring wells as floating product). For example, in a soil with a hydrocarbon concentration of 5,000 mg/kg and a C_{sat} of 50 mg/kg, 99 percent of the oil is present as NAPL.

C_{sat} is dependent on the soil properties (such as moisture content, bulk density, and porosity) and the properties of the chemical compounds. Hence, C_{sat} values vary with soil conditions and may be different above and below the water table, as shown in Table 1. Table 1 also shows the percentage of the hydrocarbon mass in the dissolved, vapor, and adsorbed phases at or below C_{sat} given ADEC default soil conditions (as described above, at most spill sites the bulk soil concentration is above C_{sat} and the majority of the hydrocarbon mass is present as NAPL). The example C_{sat} data in Table 1 show the tendency of different compounds to partition into the dissolved, vapor, or adsorbed phases. In the Table 1 example, most of the benzene mass partitions into the dissolved phase, and the majority of the DRO aliphatics partition into the adsorbed phase.

The presence of NAPL in a soil sample may best be assessed by comparing the concentrations of the relatively lower solubility hydrocarbon fractions detected at the site to their C_{sat} values. For example, in Table 1, the C_{sat} for benzene is 489 mg/kg and the C_{sat} for the C_{14} DRO aliphatics is 3 mg/kg. Experience at hydrocarbon-contaminated sites shows that benzene is rarely measured at concentrations above its C_{sat} value, but DRO aliphatics are found above their C_{sat} value at virtually every regulated diesel spill site. When NAPL of any compound or fraction is present, then all of the sparingly soluble, organic compounds tend to follow four-phase partitioning concepts, hence, four-phase partitioning exists for all of the sparingly soluble, organic compounds at virtually every regulated diesel spill site (in this document “sparingly soluble” or immiscible compounds are simply those compounds which are not infinitely soluble, nor totally insoluble; no specific concentration range is associated with the term “sparingly soluble”).

2.1.5 Raoult’s Law Background

Gasoline, diesel fuel, and crude oil are complex mixtures of hundreds of individual hydrocarbon compounds. When NAPL in a soil is composed of more than one compound, the effective solubility and vapor concentrations of the compounds vary from their pure-phase solubility and vapor concentration according to Raoult’s Law. Raoult’s Law relates the effective solubility and vapor concentration of a hydrocarbon constituent to the mole fraction of the constituent in the NAPL:

$$S_{\text{effective}} = X_i * S$$

Where S = theoretical or maximum solubility (mg/L)

X_i = mole fraction of compound X in the multi-constituent NAPL
 = (moles of X_i / total moles of NAPL)

The effect of Raoult's law is illustrated in Figure 5, which shows a layer of NAPL floating on water in a beaker. In the beaker on the left, the NAPL is 100 percent benzene and the dissolved benzene concentration in the water is 1,750 mg/L. In the center beaker, 50 percent of the moles in the NAPL are benzene, 50 percent of the moles in the NAPL are toluene, and the resulting dissolved benzene concentration in the water is 875 mg/L (half of its pure-phase solubility). In the beaker on the right only 0.05 percent of the moles in the NAPL are benzene, 99.95 percent of the moles in the NAPL are other diesel fuel constituents, and the resulting dissolved benzene concentration in the water is only 0.875 mg/L (this benzene mole fraction and solubility are representative of diesel).

Because many of the most hazardous compounds in gasoline and diesel (such as the BTEX compounds) are present as only a small fraction of the fuel mass, these compounds generally are present at only a small fraction of their theoretical solubility and volatility. Because the risk associated with the vapor-inhalation and migration-to-groundwater exposure pathways is a function of the dissolved and vapor concentrations, the failure to use Raoult's Law to assess the vapor concentration and dissolved concentration may result in overestimating the risk by several orders of magnitude.

Table 2 shows dissolved-phase BTEX concentrations in equilibrium with soils containing 5,000, 10,000, and 15,000 mg/kg of arctic diesel as calculated by the EPA three-phase partitioning equation and with four-phase partitioning equations. At the bottom of Table 2, the over-estimation of the dissolved concentration calculated by the three-phase equation is listed. In this example, the dissolved concentrations calculated using Raoult's Law are generally 1 to 2 orders of magnitude lower than those calculated using the three-phase equations. Similarly, Table 1 shows that C_{14} aromatics and C_{14} aliphatics have effective solubility values below the ADEC target soil moisture concentration calculated by equation 10 in the guidance on soil cleanup levels (ADEC, 2008b), which indicates that vadose zone DRO having ADEC default characteristics cannot cause underlying groundwater to exceed ADEC Table C DRO criteria. In other words, there is not a risk-based migration-to-groundwater cleanup level for DRO given a vadose zone, C_{14} , DRO contaminant that is either aromatic or aliphatic. Use of proper phase-partitioning calculations, including Raoult's Law, is critical to accurately represent the phase-partitioning processes and to quantitatively assess the vapor-inhalation and migration-to-groundwater pathway risks.

Sparingly soluble organic compounds are interpreted to follow Raoult's Law, so the additional compounds list was developed by removing miscible or infinitely soluble compounds and inorganic compounds from the list of compounds in Table B1 of 18 AAC 75. When hydrocarbons and other sparingly soluble compounds are present with two solvents (such as water and alcohol) the presence of the alcohol, which is infinitely soluble with hydrocarbons and water, will tend to increase the solubility of the sparingly soluble compounds. In general only alcohol blended gasolines and waste oil spills that contain significant glycol are likely to present co-solvency issues.

The four-phase partitioning following Raoult's Law is well documented in the technical literature and is used by the Washington State Department of Ecology (Model Toxics Control Act [MTCA] Cleanup Regulation, WAC 173-340-700) and the Oregon Department of Environmental Quality (ODEQ) to assess soil cleanup levels. Theoretical discussions of four-phase partitioning and the applicability of Raoult's Law are addressed in numerous research

papers (Cline et al., 1991; Lee et al., 1992; Feenstra et al., 1991; Mott et al., 1995; Mariner et al., 1997; Park and San Juan, 2000). Note that the four-phase partitioning equations described in this document are technically valid when NAPL is present, and that the three-phase soil screening equations are not valid or accurate when NAPL is present. Further, based on C_{sat} calculations, NAPL is typically present at the default GRO and DRO soil cleanup concentrations listed in Table B2 of 18 AAC 75. (The limitations of the three-phase soil screening equations are identified in the EPA *Soil Screening Guidance: Technical Background Document*, 1996).

2.2 Conceptual Model of a Fuel Hydrocarbon Spill

A conceptual site model forms a framework for collecting, interpreting, and presenting site conditions data, and a conceptual site model is a required element of the site characterization work plan. The conceptual model used in the hydrocarbon risk calculator involves an understanding of how the hydrocarbon NAPL flows through and is immobilized in the site soils; the partitioning of the hydrocarbon from the NAPL into the dissolved, vapor and adsorbed phases; and the transport of the vapor and dissolved phases away from the NAPL.

In general, hydrocarbon contaminated sites may be divided into three primary zones or areas—the NAPL-contaminated soil source area, the downgradient dissolved-phase plume area, and the unaffected area. The site characterization and risk calculation approach described in this manual is geared toward characterizing the nature, extent, and risk posed by discrete contiguous NAPL source areas (and not toward the statistical characterization of a large area or industrial zone containing multiple sources, as might be done in an EPA risk assessment). This discrete contiguous source area approach is likely conservative compared to an area-wide risk assessment, and the option to conduct an ADEC Method 4 risk assessment is always available to responsible parties.

2.2.1 Spread of NAPL Following a Release

When a hydrocarbon release occurs on the surface of unfrozen soils, the fugitive hydrocarbon tends to spread laterally across the ground surface and then to infiltrate into the soils (Figure 6). The extent of lateral spreading across the ground surface is a function of quantity and rate of hydrocarbon release and the permeability of the surface.

Similarly, when a hydrocarbon release occurs from a below grade tank or pipeline, the fuel will initially tend to spread in response to a pressure gradient around the leak location and then infiltrate (Figure 7). The infiltrating fuel from the surface spill and subsurface release tends to flow primarily vertically under the influence of gravity through larger air-filled soil pores, although capillary forces may cause some lateral spreading. If a relatively small volume of hydrocarbon is spilled, the hydrocarbon will likely be immobilized in the soil above the water table (as shown in Figures 6 and 7). If a sufficient quantity of fuel is spilled, the infiltrating fuel reaches the saturated capillary fringe, displaces some water from the saturated soil pores, and tends to migrate laterally as a mound of free product develops near the water table (Figure 8). As the water table rises and falls, the mobile free product in the vicinity of the water table encounters uncontaminated soil and tends to be smeared or trapped as immobile residual product (Figure 9).

Because some years have higher or lower water tables than other years, and because many contaminated sites are several years to a few decades old, it is likely that product will be trapped or smeared both above and below the zone of water table fluctuation observed in only a few years of study (Figure 10). At some sites the releases from several tanks or piping leaks may coalesce into a complex contiguous source area (Figure 11). Gravity drainage and flow of the hydrocarbon NAPL to a point of immobility probably occurs relatively quickly (in a period of weeks or months) at sites caused by a discrete spill event, but may occur over a period of years at sites with long-term fuel leaks. However, after the long-term leak has been stopped, any mobile hydrocarbon NAPL will likely be immobilized in a period of weeks or months.

At all NAPL spill sites, a portion of the NAPL mass in the subsurface volatilizes into the air-filled soil pores, dissolves into the soil moisture and groundwater, and is adsorbed by the soil solids (primarily the organic carbon) following the phase-partitioning relationships. Hence, the NAPL at hydrocarbon spill sites tends to act as a long-term source of dissolved- and vapor-phase hydrocarbons. The dissolved- and vapor-phase contaminants will tend to migrate away from the NAPL-contaminated soil source area (and the dissolved and vapor phase concentrations will decrease away from the source area), but the contaminant center-of-mass will not move appreciably when NAPL is present. Infiltrating precipitation encountering vadose zone hydrocarbon will tend to carry dissolved hydrocarbon toward the water table where the precipitation containing the dissolved hydrocarbon mixes with the groundwater and is advected downgradient. Similarly, NAPL in the saturated zone will tend to partition directly into the groundwater and the dissolved hydrocarbons will be advected downgradient. Vapor-phase hydrocarbon tends to diffuse toward the ground surface and into the atmosphere and nearby buildings. At some point downgradient of the spill location, the groundwater will discharge to and mix with surface waters (that is, a lake, a stream, or the ocean). Biodegradation of fuel hydrocarbons will likely occur throughout the contaminated zone (in the vadose zone and in the saturated zone) and limit the extent of migration.

2.2.2 Identification of the NAPL-contaminated Soil Source Area

As described above, it is desirable to identify the “NAPL-contaminated soil source area,” which is defined as the contiguous, three-dimensional volume of soil that contains NAPL. Within the NAPL-contaminated soil source zone, four phases are present and fuel hydrocarbons will partition into soil moisture, groundwater, soil gases, and soil organic carbon to establish a local equilibrium with the NAPL, as described by the four-phase equations with Raoult’s Law. The risk calculated using the hydrocarbon risk calculator is, in concept, the risk posed by the NAPL-contaminated soil source area. Hydrocarbon concentrations in all phases should be higher within the NAPL-contaminated soil source area than in the surrounding three-phase areas. In addition, the NAPL-contaminated soil source is the likely remediation target if a remedial action is required. Assessment of intrinsic remediation requires an understanding of the extent of the NAPL-contaminated source area.

The NAPL-contaminated soil source area may be identified by compiling and reviewing the existing laboratory test results, soil log callouts of contaminated soils, field screening data (such as photoionization detector [PID] head space readings of soil samples), groundwater test results, and sampling notes. In addition, the location and depth (or elevation) of the data should be posted on maps or cross sections of the site. The laboratory results and field screening data

may then be segregated based on whether they indicate the presence of NAPL. Indicators of the presence of NAPL include the following:

- DRO soil test results above about 10 to 50 mg/kg and GRO soil test results above about 200 mg/kg may generally be interpreted to indicate the presence of NAPL. Although DRO NAPL exists at concentrations above about 10 to 50 mg/kg, it is advised to use a working definition of the NAPL source area for DRO and GRO source areas as the area above the ADEC Table B2 migration to groundwater screening levels of 230 to 300 mg/kg, depending on the precipitation zone. For RRO source areas it is advised to use a working definition of NAPL contaminated soil source area as the area with RRO concentrations above about 250 mg/kg (although C_{sat} calculations tell us that NAPL is present at much lower concentrations and Table B2 migration to groundwater screening levels are above 8,000 mg/kg).
- PID head space readings of thousands of parts per million (ppm) at recent gasoline spill sites, hundreds of ppm at recent diesel spill sites and old gasoline spill sites, and tens of ppm at old diesel spill sites likely indicate the presence of NAPL.
- Soil samples that have a hydrocarbon odor
- Soil samples that are reduced when surrounding samples display oxidized conditions
- Soil samples that show black or gray staining or an iridescent sheen when saturated
- Soil samples that fluoresce under ultraviolet light or fluoresce during a laser-induced fluorescence (LIF) survey
- Observations of free product on the water table in monitoring wells
- Water samples results above solubility limits—in particular, water samples with DRO concentrations above about 4 or 6 mg/L
- Water samples that have a sheen

The sample locations that exceed or do not exceed these criteria will define the NAPL-contaminated source area (on both maps and cross sections, a boundary may be drawn separating the NAPL-contaminated soils from the soils that do not contain NAPL). Knowledge about the mechanics of migration of NAPL in the vadose zone and near the water table surface and the fluctuation of the water table will help identify the NAPL-contaminated soils. The distribution of hydrocarbon will likely be similar to one shown in Figures 6 through 11. Note that soil concentrations within the NAPL-contaminated soil source zone may vary significantly in concentration and that there can be some uncontaminated samples within the NAPL-contaminated soil source zone. These conditions are illustrated in Figure 12, which shows red-dyed hydrocarbon infiltrating through a tank filled with white sand. As shown in Figure 12, Samples A through C are within the NAPL-contaminated soil source area, but Sample A has a much higher concentration than Sample B, and Sample C is uncontaminated. Because of this variability, it is generally not necessary to contour hydrocarbon concentrations within the NAPL-contaminated source area.

In general, most of the NAPL within the NAPL-contaminated soil source area is present as discontinuous blobs, ganglia, and pendular rings and will not collect on the water table in monitoring wells. The presence of free product in site monitoring wells indicates that

continuous NAPL is present and it will be necessary to measure the free product thickness during a period of sustained low groundwater to assess the maximum or near maximum thickness of oil that may accumulate at the site. The area where free product is observed in monitoring wells should be identified on site maps. The area can be identified by drawing a boundary separating the wells containing the NAPL from those that don't. Some monitoring wells from inside this area of suspected continuous NAPL may not show oil on the water table. In addition, the thickness of NAPL observed should be measured and compared to the "Charbeneau thickness" for the soil texture present at the water table to help assess whether the oil is mobile at the NAPL source area scale. (The Charbeneau thickness is the thickness of oil in a monitoring well that is required to overcome the pore entry pressure of the formation soils, as described in a peer reviewed article in *Ground Water and Remediation* (Charbeneau, et. al. 2000) and in American Petroleum Institute (API) Publication 4682 [Charbeneau et al., 1999]; and as described in the SOC paper *Maximum Allowable Concentration, Residual Saturation, and Free Product Mobility* [Geosphere and CH2M HILL, 2006d]).

Additional information on the presentation of site characterization data and examples of data tables and site maps is provided in Appendix A. Copies of the spreadsheets used to generate tables similar to those in Appendix A may be downloaded from the ADEC web page.

Hydrocarbon Risk Calculator Overview

3.1 Forward and Backward Risk Calculations

Human health risk calculations combine phase-partitioning equations, fate and transport equations, and human exposure equations to calculate risk and/or cleanup levels. Two general types of calculations are possible – forward calculations and backward calculations. Forward calculations assess the risk caused at some exposure point within or downgradient of the contaminant source area. Backward calculations assess the concentration of a contaminant in the source area that causes or creates some (acceptable) level of risk at an exposure point in or downgradient of the contaminant source area. Forward calculations are most useful for assessing risk. Backward calculations are useful for setting screening levels.

When multiple contaminants and/or multiple exposure pathways are present, backward-calculated screening levels typically do not represent true “risk-based cleanup levels” because the backward calculation usually only accounts for one compound and one exposure route; hence, if there is more than one contaminant, the cumulative risk will likely exceed the allowable risk level when the screening level concentration for any one chemical is reached. In addition, when multiple contaminants and/or multiple exposure pathways are present, there is not a “unique” back-calculated soil cleanup level.

Because of the difficulty in calculating “risk-based cleanup levels” for sites with multiple contaminants and multiple exposure pathways, the hydrocarbon risk calculator, as discussed in this manual, uses existing source area concentrations as model input and performs a forward calculation of risk for each compound and each exposure route. In addition, cumulative risks are calculated in the hydrocarbon risk calculator model. If the risk exceeds acceptable levels, then the hydrocarbon risk calculator may be used iteratively to conduct backward calculations of alternative cleanup levels by reducing chemical concentrations used as input into the calculator in a manner reflective of a remedial approach (e.g., soil vapor extraction would tend to remove relatively volatile compounds at a much higher rate than the relatively non-volatile compounds).

3.2 Hydrocarbon Risk Calculator Workbook Layout

The hydrocarbon risk calculator is part of a Microsoft Excel™ workbook. The basic workbook, as downloaded from the ADEC web page, contains nine worksheets. The worksheets contain the following:

- **Chemical Properties** – This table lists and/or calculates the chemical properties values used in the risk calculations. The compounds listed on the worksheet include the BTEX and PAH compounds and a list of about 120 sparingly soluble organic compounds that may be present as constituents of the multi-constituent NAPL. Values presented in this worksheet include the solubilities, vapor pressures, Henry’s constants, and K_{oc} values for the aromatic

and aliphatic, equivalent-carbon groups. The temperature-adjusted Henry's constant are calculated for all compounds by using the Clausius-Clapeyron equation following EPA guidance (2001). The values in this table may be updated periodically by the ADEC, but are locked to the general user.

- **Exposure Parameters** – This table lists the ADEC default exposure parameters documented in the ADEC *Cleanup Levels Guidance* document (2008b). These default exposure parameters are used in the residential and industrial exposure scenarios. The values in this table will be updated periodically by the ADEC, but are locked to the general user.
- **Slope Factors and Reference Doses** – This table lists the slope factors and reference doses/reference concentrations used in the risk calculations. The values in this table will be updated periodically by the ADEC, but are locked to the general user.
- **Soil Data from EPA** – This table contains basic soil property data from the EPA Johnson and Ettinger model and is provided for information purposes only. The values in this table are locked.
- **Four-phase, Cumulative Risk Calculations** – This worksheet contains the primary site-specific input and output from the hydrocarbon risk calculator. Information about this worksheet is the focus of the remaining portions of this user manual.
- **Dilution-Attenuation Factor** – The dilution-attenuation calculations are performed and displayed in this worksheet. Input values for the DAF worksheet are pulled from other worksheets in the calculator.
- **Site Visitor and Trench Worker** – This worksheet characterizes risks to trench workers and site visitors and is presented in addition to the default residential and industrial scenarios. The exposure parameters may be adjusted by the user working with the ADEC. This optional worksheet is presented primarily as a risk communication and risk management tool. It may be used to characterize risks to site visitors and to identify the need for institutional and engineering controls when residential criteria are exceeded but there is not residential land use. The trench worker risk calculations are to help plan work when excavation is a potential remedial approach and to provide information for future site improvement work.
- **CSM Coordinates** – This worksheet presents a pictorial conceptual site model that shows the source zone, infiltration and groundwater flow lines through the source, seasonal high and low groundwater levels, uncontaminated soil layers overlying the source, the house or other occupied structure used as input to the Johnson & Ettinger vapor intrusion calculations, and the hypothetical drinking water well used in the migration-to-groundwater calculations. The CSM may be used to graphically summarize site conditions that are used in the risk calculations and to check that the input values are what the user intended.
- **Input and output summary** – This worksheet lists the hydrocarbon risk calculator input parameter values and selected output data in a single column. The work sheet may be used to build a data base documenting the conditions and risk at the sites addressed by the HRC.

3.3 Hydrocarbon Risk Calculator Worksheet Layout

The hydrocarbon risk calculator “4-phase, cumulative risk calculations” worksheet contains most of the site-specific input and output from the hydrocarbon risk calculator. The hydrocarbon risk calculator worksheet is divided into 12 primary sections, and the default printout of the hydrocarbon risk calculator is 12 pages long with 1 page printed for each section of the calculator. (These sections are also referred to as pages.) The printed output of the calculator summarizes the results of each section of the calculator; however, there are additional intermediate calculations not shown in the printout. Table 4 is an example of the calculator output. The sections are identified with column headings with different colors. The cells requiring input data are highlighted in light yellow; all other values are fixed or calculated by the spreadsheet. Because the calculator is locked, only the light yellow cells containing input parameter values may be changed (although all of the equations in the calculator may be viewed). The purpose and type of calculations performed in each section are described below. (The following discussion assumes that the reader has the spreadsheet and is familiar with ADEC regulations and guidance documents.)

- Section 1 (Page 1) shows the hydrocarbon exposure point concentrations in soil and groundwater and the soil and groundwater conditions used as model input values.
- Section 2 (Page 2) shows the soil and building parameters used as input to the Johnson and Ettinger model.
- Section 3 (Page 3) summarizes the concentration and distribution of each hydrocarbon fraction in the dissolved, vapor, adsorbed, and NAPL phases. The aromatic and aliphatic, equivalent-carbon character of the spilled fuel may be adjusted to match site-specific conditions by changing values in the light yellow cells.
- Sections 4 through 8 (Pages 4 through 8) list the risks associated with different exposure pathways. Residential site risks are shown on the left side of the table, and industrial site risks are shown on the right side of the table.
 - Section 4 (Page 4) contains the soil-ingestion pathway risks and soil compliance levels for each compound or hydrocarbon fraction.
 - Section 5 (Page 5) contains the outdoor-air vapor-inhalation pathway risks for each compound or hydrocarbon fraction.
 - Section 6 (Page 6) contains the indoor-air vapor-inhalation pathway risks for each compound or hydrocarbon fraction.
 - Section 7 (Page 7) contains the calculated migration-to-groundwater pathway risks for each compound or hydrocarbon fraction.
 - Section 8 (Page 8) presents the groundwater-ingestion risks for each compound or hydrocarbon fraction based on the measured concentrations in groundwater samples.
- Section 9 (Page 9) contains the results of the potential cumulative risk calculations assuming that all pathways are complete. Residential site risks are summarized on the

left side of the table, and industrial site risks are summarized on the right side of the table.

- Section 10 (Page 10) contains the results of the potential current cumulative risk calculations (The potential current cumulative risk is the risk from the exposure pathways at the site that are complete at this time.) Residential site risks are summarized on the left side of the table, and industrial site risks are summarized on the right side of the table.
- Section 11 (Page 11) assesses whether contaminated soil from the site has the potential to cause surface water to exceed the ambient water quality criteria or groundwater to exceed groundwater-ingestion criteria. The information could be used to assess limitations on the placement of the contaminated soil if the contaminated soil was excavated and transported offsite.
- Section 12 (Page 12) summarizes the site status based on the requirements of 18 AAC 75.

SECTION 4

Hydrocarbon Risk Calculator Input

Input parameters for the hydrocarbon risk calculator are discussed in this section, and input parameters units and ranges are summarized in Table 3. The cells requiring input data are highlighted in light yellow; all other cells in the calculator are locked (i.e., set at default values or calculated by the spreadsheet given the input parameters). The majority of the data input values are entered into the first three sections (pages) of the four-phase tab of the calculator workbook. It is important to note the units for the input values and to only use values in the proper units as model input. Many calculations are updated as new data are entered into the calculator; however, **the phase partitioning and risk calculations are only updated when the “calculate button” is clicked.**

4.1 Section 1 (Page 1) – Hydrocarbon Concentration and Soil and Groundwater Conditions Input Parameters

The first section is for the input of the site-specific data such as hydrocarbon concentrations, soil parameters, and aquifer data.

4.1.1 Soil Concentrations

The soil concentrations used as input to the hydrocarbon risk calculator should typically be the 95 percent upper confidence limit (UCL) on the mean concentration of the samples collected within the NAPL-contaminated soil source area or the maximum concentration measured at the site. The NAPL-contaminated soil source area is the three-dimensional volume of soil containing NAPL, and may be delineated as described in Section 2 and Appendix A of this user manual. The preferred tool for calculating the 95 percent UCL value is the EPA software program “ProUCL,” which can be downloaded for free, from the EPA web site (www.epa.gov). If sufficient data are not available to calculate a 95 percent UCL, the highest soil concentrations measured at the subject site may be used as input, although maximum concentrations are likely less representative of the exposure point concentration than the 95 percent UCL.

Only numeric values may be used as input for the BTEX, GRO, DRO, and RRO input concentrations. If a compound or hydrocarbon fraction was not detected, then a substitute value of the detection limit may be used as the default input to the 95 percent UCL calculation and/or to the HRC. For PAHs, either a measure of the PAH exposure point concentration or an “ND” (not detected) may be input. If an ND value is used as input, risk will not be calculated for the compound. For PAHs, DEC guidance conservatively requests that either a measured result or a value equivalent to the detection limit be used, rather than “ND.” If an unacceptable risk level for the site is generated, and PAHs are not expected at the site, the calculation can be revised, based on consultation with ADEC.

The test methods for quantifying the hydrocarbons include the following: AK101 for gasoline-range hydrocarbons, AK102 for diesel-range hydrocarbons, AK103 for residual-

range hydrocarbons, EPA Methods 8021 or 8260 for BTEX; and EPA Method 8270 SIM for the PAH concentrations. Data from older analytical test methods such as EPA Methods 8015, 8100 and Method 418.1 are interpreted to be representative (8015 and 8100) or conservative (418.1) measures of the source area concentrations and are valuable for delineating the NAPL-contaminated soil source area. In addition, data from the EPA method 8015 and 8100 tests that identify the hydrocarbon range quantified may be used in calculating the 95 percent UCL, with the concurrence of the ADEC.

To document the site conditions and support the soil concentration used as input to the calculator, it is recommended that the following be prepared:

- A map and cross section depicting the NAPL-contaminated soil source area and all sample locations
- A table summarizing all soil sample results from the site
- A table summarizing results from the NAPL-contaminated soil source area

A format for summarizing NAPL source area data is shown in Appendix A and in the technical paper *Site Conditions Summary Report for Hydrocarbon Risk Calculations and Site Status Determination* (Geosphere and CH2M HILL, 2006g).

The HRC calculates risk posed by seven additional non-carcinogens and seven additional carcinogens (beyond the BTEX and PAH compounds) that may be encountered as constituents of the hydrocarbon NAPL. Sparingly soluble organic compounds which are present at more than 10% of their soil direct contact or outdoor air inhalation levels should be included in the risk calculations. To add the additional compounds it is advised that user copy the compound name(s) from the “Additional Compounds Library” in the chemical properties tab and then use the “special paste, values” function to enter the compound names in cells A34 through A47 in the HRC. Note that compounds which have both carcinogenic and non-carcinogenic properties must be entered twice – once as a carcinogen and once as a non-carcinogen. The soil and groundwater concentrations and the dissolved phase half life values are then entered the same as for the BTEX and PAH compounds. The HRC uses the VLOOKUP function to select the compound properties and applies the same risk calculation approaches as used for the BTEX and PAH compounds.

4.1.2 Soil Aromatic Fractions

The fraction of the hydrocarbon mass within the GRO, DRO, and RRO ranges that is composed of aromatic compounds may be derived from site-specific analyses by using the AK101, AK102 and AK103 aromatic and aliphatic test methods or the Washington State VPH and EPH test methods. Site specific EPH and VPH data are required to assess the character of the GRO, DRO and RRO concentrations from the AK methods unless the ADEC approves the use of an alternative aromatic and aliphatic equivalent carbon characterization (the ADEC is assessing the use of a conservative default and/or fresh fuel characterization).

The primary objective of the VPH and EPH testing is to characterize the spilled hydrocarbon in aromatic and aliphatic, equivalent-carbon groups and not to delineate extent. Therefore, the VPH and EPH analyses should be conducted on samples known to be relatively heavily contaminated based on field screening data or previous GRO, DRO, and RRO testing. Note

that the aromatic mass fraction is used as input to the calculator (not the percentage of aromatics – the input value must be less than 1). A format for reducing VPH and EPH data is discussed in Appendix A. ADEC default assumptions for the aromatic fraction are listed for reference, but none of the diesel fuels evaluated in the technical paper had aromatic fractions as high as the default ADEC assumptions.

4.1.3 Groundwater Concentrations

The groundwater concentrations used as input are the maximum concentrations measured within the NAPL source area. The test methods used to measure the dissolved concentration are the same as those listed above for soil.

The water samples should be collected to be representative of the dissolved-phase concentrations at the site and, hence, should not incorporate NAPL (or sheen). Sampling methods that minimize or eliminate the incorporation of NAPL include low-flow sampling, which does not allow water table drawdown to the intake level, ice encapsulation of the intake tubing, and the use of diffusion bag samplers for volatile organic compounds (VOCs). (Diffusion bag samplers are not approved for DRO and EPH analyses.)

Gasoline and diesel range dissolved aromatic and aliphatic concentrations from the VPH and EPH test data should be entered when available, and it is recommended that source area water samples be analyzed by these methods at virtually every site. This approach is recommended because the VPH and EPH analyses are interpreted to provide a measure of only the dissolved-phase aromatic and aliphatic concentrations while the AK102 DRO test method also measures biogenic and partially biodegraded hydrocarbon compounds. The VPH and EPH test methods directly quantify the aromatic and aliphatic concentrations and use a silica gel cleanup to remove polar compounds. (This removal of polar compounds is particularly important for the DRO or EPH ranges.) The direct quantification of aromatics and aliphatics is important because these values are the foundation for the risk calculations. No reference doses are available for total GRO, DRO or RRO, but reference doses and risks are associated with aromatic and aliphatic, equivalent-carbon groups. Therefore, the groundwater ingestion “risk calculations” for GRO, DRO and RRO are based on the GRO, DRO and RRO aromatic and aliphatic concentrations measured within that spill. For these reasons, when GRO, DRO and RRO aromatic and aliphatic concentrations are entered as input to the hydrocarbon risk calculator, the aromatic and aliphatic values (not the total GRO, DRO or RRO values) are used to calculate groundwater-ingestion risk. If GRO, DRO and RRO aromatic and aliphatic concentrations are not entered into the hydrocarbon risk calculator, the total GRO, DRO or RRO values are used to calculate groundwater-ingestion risk (the aromatic concentration is conservatively assumed to equal the total concentration and the aliphatic concentrations is conservatively assumed to equal half the total concentration).

Dissolved phase half life values are entered into the calculator in the columns next to the dissolved phase concentration. The half life values are used in characterizing migration to groundwater and are discussed further in Appendix A.

4.1.4 Soil Properties

Several soil properties are used in the phase-partitioning calculations and the migration-to-indoor and migration-to-outdoor-air risk calculations. Example soil property values for various soil types are listed in the soils data tab of the calculator (from the EPA Johnson and Ettinger model). The soil property input values are ideally derived from the geotechnical laboratory analysis of samples collected at the subject site. Soil properties used as input to the calculator are briefly discussed below, and American Society of Testing and Materials (ASTM) test methods are listed in Table 3.

- Soil bulk density is a measure of the weight of the soil particles per unit volume of the porous media (grams per cubic centimeter [g/cm^3] or pounds per cubic foot [lb/ft^3]). The soil bulk density or soil unit weight is usually measured by driving a cylindrical sampler (e.g., a brass liner) into site soils to extract a relatively undisturbed soil sample and measuring the wet and dry weights of the known volume of soil.
- The gravimetric moisture content of the soil is calculated from the wet and dry soil weights. Representative moisture content data may be obtained from geotechnical analysis of bulk soil samples collected from the vadose zone. Soil moisture content data provided with chemical laboratory analytical results are typically based on only a relatively small soil volume and may yield less representative data than larger volumes samples analyzed by ASTM methods.
- The specific gravity of the soil is a measure of the density of the soil solids normalized to the unit weight of water. It can be measured using ASTM methods, or a default value of 2.65 may be used.
- The fraction of organic carbon (f_{oc}) is a measure of the fraction of the total soil solids weight that is organic carbon and should be measured in uncontaminated soil samples collected from NAPL source zone strata and in the aquifer downgradient of the source (ADEC, 2008e).
- The soil temperature input should be representative of the NAPL-contaminated soil source zone and may be obtained by measuring onsite soil and/or groundwater temperatures.

The total porosity is calculated by the HRC based on either a measured or estimated specific gravity of the soil solids and the soil bulk density. The water-filled porosity is calculated by the HRC from the soil moisture data and the air-filled porosity is calculated from the total porosity and water-filled porosity data.

If site-specific soil properties data are not available, then the ADEC default assumptions for these parameters may be used as input. The soil samples tested to measure the bulk density, specific gravity, and moisture content may be collected from within the NAPL-contaminated soil source area or from the same strata in an uncontaminated portion of the site. The soil samples collected for f_{oc} analyses must be collected from outside the NAPL-contaminated soil source area but should be from the NAPL-contaminated soil source area strata and from the aquifer in the downgradient dissolved-phase plume.

In addition to these soil properties, a representative characterization of the soil stratigraphy, supported by sieve analysis of several samples, is recommended to help better understand and document the site conditions. (Sieve analysis of soil samples collected from the shallow saturated zone are particularly valuable to help estimate hydraulic conductivity if slug tests and/or pump tests are not performed.)

4.1.5 Hydrogeologic Conditions

Hydrogeologic condition data, including the hydraulic conductivity, aquifer saturated thickness, flow direction, hydraulic gradient, and source thickness, are used most directly in calculation of a DAF associated with the migration-to-groundwater pathway, but are also basic and critical site-characterization data. The DAF is a measure of the change in the dissolved concentration between the NAPL source zone and the groundwater in the mixing zone at the downgradient edge of the source area.

The migration-to-groundwater calculations evaluate whether the soil concentrations are likely to cause groundwater contamination above a maximum contaminant level (MCL) or a groundwater-ingestion risk-based concentration over an interval of aquifer that may be used as a source of drinking water. The DAF in the hydrocarbon risk calculator uses a Summers mixing box model calculation that assumes a fixed mixing zone depth; accounts for the presence of NAPL in the vadose, seasonally saturated, and/or saturated zones; and allows representative biodegradation in the saturated zone. The mixing zone or migration-to-groundwater compliance zone is represented by a hypothetical drinking water well located at the downgradient edge of the source area, as shown in Figure 1 of Appendix B. (This location for the fixed mixing zone is the most conservative.) The mixing zone or hypothetical drinking water well screen has a fixed depth extending 18 feet below the seasonal low water table (or to the bottom of the water table aquifer, if the water table aquifer is less than 18 feet thick). The DAF is described in greater detail in Appendix B. Following are brief discussions regarding data that are used to define the hydrogeologic conditions used as input to the HRC.

- Several methods are available to measure or estimate the hydraulic conductivity, such as conducting pumping tests or slug tests, permeameter testing of soil samples, and estimating the conductivity based on sieve analyses. Slug tests and small-scale pump tests using 2-inch monitoring wells and water level transducers with data loggers can be accomplished in about 2 to 4 hours and offer valuable data relative to the time invested. The slug test and/or small-scale pump test data can be readily reduced and documented using any of several commercially available aquifer test analysis software programs, spreadsheets, or hand calculations.
- At the lowest level of effort, the groundwater gradient and flow direction may be determined by measuring the depth to groundwater in a minimum of three monitoring wells, using swing ties and a level survey to establish the location and collar elevations on the monitoring wells, then using a graphical technique (Fetter, 1986) to calculate the flow direction and gradient. If the site is large (10,000+ square feet), then more than three wells will likely be necessary to document the gradient and characterize the extent of the dissolved-phase plume. In general, as many wells as possible should be used to document the gradient and flow direction. (For example, if a site has eight monitoring

wells, all of them – not just three monitoring wells – should be gauged and used to assess the flow direction and gradient.)

- When more than three wells are used to assess the flow direction, the groundwater potentiometric surface, hydraulic gradient, and flow direction may be characterized by using a surface contouring program, such as Surfer® (Golden Software). Any computer-generated contours should be reviewed and revised by a qualified person before they are finalized. When contouring programs such as Surfer® are used, the well locations from which the contoured data were derived should always be highlighted, and blanking files should be used to limit the display of contours outside the area of data. (The contouring algorithms commonly cause the contours to misleadingly splay apart outside the area of the monitoring wells.)
- When calculating the gradient, it is desirable to show the location or locations that were used in the calculation. Provided the soils are isotropic, the groundwater flow direction is generally assumed to be perpendicular to the groundwater contours. The groundwater Darcy velocity may be calculated as the hydraulic conductivity multiplied by the gradient, and the advective velocity may be calculated as the Darcy velocity divided by the effective porosity.
- The source length may be scaled off site maps showing the NAPL-contaminated soil source area and the groundwater contours. The source length should be measured in the direction of groundwater flow.
- The aquifer saturated thickness may be determined when the saturated thickness is relatively thin and penetrated by site investigation borings extending 10 or 20 feet below the water table. Otherwise, the thickness of the aquifer may be estimated by using data from other borings (such as geotechnical borings for adjacent structures), drillers' logs of water wells, and/or geologic studies of the area.
- The distribution of NAPL-contaminated soil relative to the water table and the seasonal fluctuation of the water tables are described by entering the depth to the seasonal low water table, the seasonal water table fluctuation and the depth to the top and bottom of NAPL-contaminated soil. These data may be derived from water level measurements during periods of low and high water, from soil boring logs that indicate the presence of mottled soils or reduced soils, and from the distribution of contaminated soils in the suspected zone of seasonal water table fluctuation. The distribution of NAPL-contaminated soils in the zone of seasonal water table fluctuation may be assessed from laboratory results indicating the presence of NAPL (e.g., DRO concentrations above 50 mg/kg), soils samples with significant PID readings, visually stained soils, and soils samples with a fuel odor.
- Precipitation data may be obtained from the National Weather Service, National Oceanic and Atmospheric Administration, and Alaska Environmental Information Data Center. The precipitation rate is used to estimate infiltration by assuming that infiltration is 20 percent of precipitation. This default assumption is thought to be reasonable or slightly conservative for sites with coarse-grained soils (i.e., infiltration will often be less than 20 percent of precipitation) but may be overly conservative for sites with fine-grained surficial soils and/or steep slopes (where infiltration may only be 2 percent of

precipitation). Therefore, an infiltration rate derived from direct measurements, published studies, or an infiltration model may be entered into the HRC.

- The parameters used in the attenuation calculation include dissolved-phase half-lives for the compounds and hydrocarbon fractions being assessed. The half-life information may be derived from concentration data collected in the downgradient dissolved-phase plume at the subject site or literature values. If half-life information is not entered, then a default half-life of 100,000 days may be used in the calculations to calculate a conservative DAF (the 100,000 day half life is an arbitrary value which indicates a very low biodegradation rate yielding an attenuation factor near 1).

The hydrocarbon risk calculator was developed with the understanding that NAPL-contaminated soil is present in the seasonally saturated or saturated zone at the majority of hydrocarbon spill sites. As indicated by the preceding discussion, when evaluating risk, designing remedial systems, and selecting institutional controls, it is critical to accurately assess whether NAPL is present in the permanently saturated zone or the zone of seasonal water table fluctuation. Therefore, it is recommended to emphasize the collection of soil samples in the zone of seasonal water fluctuation and the installation of a least one monitoring well at the location most likely to be affected by NAPL (typically, this would be directly below the release point—the underground storage tank or leaking pipe) when conducting site investigations. More information on the delineation of the NAPL-contaminated soil source zone is provided in Appendix A and in the technical papers *Site Conditions Summary Report for Hydrocarbon Risk Calculations and Site Status Determination* and *Groundwater Sampling Techniques for Site Characterization and Hydrocarbon Risk Calculations* (Geosphere and CH2M HILL, 2006g and 2006e, respectively).

The HRC uses the input data to characterize whether a vadose zone or smear zone or saturated source zone is present following the “Vadose Zone or Smear Zone Source?” prompt. A value of 4 is shown when the NAPL-contaminated soil source zone is entirely within the vadose zone, and a value of 1 is shown when the source is in the smear zone of saturated zone. If a saturated zone source is indicated, then the measured source zone groundwater concentrations are interpreted to be a more representative measure of equilibrium partitioning than the calculated solver solution. The measured dissolved-phase concentrations are used to calculate vapor-phase concentrations for input to the Johnson and Ettinger vapor intrusion calculations (rather than the solver NAPL-vapor equilibrium concentrations), and the measured dissolved-phase concentrations are used to assess whether the contaminated soils would likely cause groundwater or surface water criteria exceedances if excavated and transported to another location.

4.1.6 Potable Water Characterization

If the groundwater at a site is non-potable, then a groundwater-ingestion risk is not calculated or included in the cumulative risk calculation for the site (i.e. if the groundwater is classified as non-potable, then the fraction of risk is listed as zero). To indicate that the groundwater at a site is potable, a value of “1” should be entered at the prompt. To indicate that the groundwater at a site is non-potable, a value of “10” should be entered at the prompt (note that the numeric value “10” is simply an indicator that the groundwater has been determined to be non-potable and is not associated with the repealed “10x rule”). For groundwater to be described as non-potable in the hydrocarbon risk calculator, the ADEC

must make a determination that the groundwater is non-potable, as stipulated in 18 AAC 75.350.

4.1.7 Exposure Routes Complete at Present Time

The hydrocarbon risk calculator calculates the potential cumulative risk assuming that all pathways are complete and the cumulative risk for the pathways that are complete at the present time. Pathways that are complete at the present time are indicated by entering a “1” at the appropriate prompt, and incomplete pathways are indicated by entering a “0” at the prompt in the gold-colored block of cells on Page 1 of the calculator.

The calculation of risk associated with the pathways complete at the present time is to help prioritize risk management actions (remediation, engineering controls and/or institutional controls). For example, a site that has an unacceptable risk from the exposure routes complete at the present time would likely be a higher priority site for remediation, engineering controls, and/or institutional controls, than would a site where the risk from the exposure routes complete at the present time is within the acceptable range. The cumulative risk associated with the pathways complete at the present time is typically not used for closure decisions. The determination of which pathways are complete at the present time should be relatively straightforward – for example, if there are no drinking water wells onsite, then the groundwater-ingestion pathway is not complete at the present time. Similarly, if there are no occupied buildings at the site, then the migration-to-indoor-air pathway is incomplete at the present time. The assessment of pathways that are complete at the present time may be done in conjunction with development of a site conceptual model.

4.1.8 Climate-related Exposure Parameters for Outdoor Air Inhalation and Soil Ingestion

The ADEC uses differing exposure assumptions depending on the climatic conditions (precipitation and length of the freezing season) at the site and whether residential and industrial site conditions are being assessed. The appropriate ADEC exposure frequency and “Q/C” value for the site being evaluated are selected by the HRC based on the climatic zone entered by the user. At the prompt, one of the following values should be input: 1 to indicate the site is in the under 40-inch precipitation zone; 2 to indicate the site is in the over 40-inch precipitation zone; or 3 to indicate the site is in the arctic zone.

4.2 Section 2 (Page 2) – Migration-to-indoor-air Model Input Parameters

Section 2 (Page 2) of the hydrocarbon risk calculator is for the input of soil and building parameters used in the characterization of risk associated with the migration-to-indoor-air exposure pathway. The “EPA advanced soil gas” Johnson and Ettinger model for vapor intrusion is used to characterize the human health risk. As described above, the light yellow cells are for the input of site-specific data and all other required values are calculated by the spreadsheet. The soil input parameters associated with the Johnson and Ettinger model input are to characterize the uncontaminated soils between the contaminated source and the building foundation.

The Johnson and Ettinger model in the hydrocarbon risk calculator allows up to three soil layers with different properties between the source and the building. If fewer than three different soil layers are present, then the same input properties should be used for two or more layers, but note that a positive thickness must be entered for each soil layer. Also, note that the sum of the soil layer thicknesses must be greater than the depth of the bottom of the basement slab or floor slab. The geotechnical characterization of the soils should be supported by boring logs and soil testing using the ASTM methods listed in Table 3 for the contaminated soils. The diffusion of hydrocarbon vapors from a source area to the building foundation and the advection of the vapors into the building are very dependent on the soil properties; hence, only well-documented, representative values or conservative values should be used as model input.

If a building is currently on the subject site, then building properties representative of that structure should be used to assess vapor-intrusion risks. Otherwise, it is recommended that EPA default building parameters be used for input. The EPA default building parameter values are listed to help ensure that reasonable input values are used. EPA documents provide a sensitivity analysis for the Johnson and Ettinger model input parameters (Environmental Quality Management, Inc., 2004).

4.3 Section 3 (Page 3) – Hydrocarbon Character Input to the Phase Partitioning Calculations

The third section of the spreadsheet performs the phase-partitioning calculations and assesses whether a three- or four-phase hydrocarbon distribution is present. Input data to this section of the calculator are used to characterize the distribution of GRO, DRO, and RRO into aromatic and aliphatic, equivalent-carbon groups. Appendix A provides additional information about the characterization of the hydrocarbon, and a spreadsheet that may help summarize the VPH and EPH data for input to the risk calculator is provided on the ADEC web page.

The data entered in the yellow-highlighted cells in Section 3 of the calculator are the fraction of the DRO aromatic mass within the listed equivalent carbon ranges, the fraction of the GRO aliphatics within the listed equivalent-carbon ranges, and the fraction of the DRO aliphatics within the listed equivalent-carbon ranges. The sum of the DRO aromatic fractions must equal 1, the sum of the GRO aliphatic must equal 1, and the sum of the DRO aliphatic fractions must equal 1 (cells D87 to D90 provide a check that the sum of the fractions equals 1).

The fraction of the GRO and DRO mass within aromatic and aliphatic, equivalent-carbon ranges may be derived from site-specific analyses using the Washington State VPH and EPH test methods. Site specific EPH and VPH data are required to assess the character of the GRO, DRO and RRO concentrations from the AK methods unless the ADEC approves the use of an alternative aromatic and aliphatic equivalent carbon characterization (the ADEC is assessing the use of a conservative default and/or fresh fuel characterization).

As described above, the primary objective of the VPH and EPH testing is to characterize the spilled hydrocarbon in aromatic and aliphatic, equivalent-carbon groups and not to delineate extent. Therefore, the VPH and EPH analyses should be performed on samples

known to be relatively heavily contaminated based on field screening data or previous GRO, DRO, and RRO testing. Note that mass fraction values are used as input to the calculator (the percentage of aromatics is not used – the input value must be less than 1).

4.4 Additional Model Input

Model input values may be entered in two additional locations other than Sections 1, 2, and 3 of the hydrocarbon risk calculator, as follows:

- Soil gas concentrations for the Johnson and Ettinger vapor intrusion risk calculations may be entered directly into the calculator in Section 6. If soil-gas concentrations are entered into the model, they take precedence over the calculated NAPL-vapor equilibrium concentrations and groundwater-vapor equilibrium concentrations. Soil-gas sample collection protocols are available from the EPA, Air Force Center for Environmental Excellence (AFCEE), and the California Department of Environmental Conservation. The ADEC also has produced *Draft Vapor Intrusion Guidance* (2009) discussing collection of soil-gas samples. If soil-gas data are used as input to the Johnson and Ettinger model, then the soils data input in Section 2 of the hydrocarbon risk calculator should reflect the sample depth, soil character, and soil strata thicknesses between the soil-gas samples and the bottom of the building slab.
- Exposure parameters for the optional trench worker and site visitor scenarios are defined on the Excel worksheet page for those scenarios.
- Industrial and/or commercial site workers are assumed to be at the work site 250 days per year as listed in the Cleanup Levels Guidance (2008b) and as shown in the exposure parameters tab of the HRC. However, the workers are typically not present at the work site for 24 hours per day; therefore, an additional input value has been added to the outdoor air inhalation exposure parameters to allow the HRC user to specify the representative number of hours per day that the worker is on site. The exposure hours per day value is input in the light yellow highlighted cells on the exposure parameters worksheet.
- Chemical specific properties are provided in the chemical properties worksheet of the HRC and cannot be modified by the user, except for the representative “equivalent carbon number” for the various aliphatic and aromatic equivalent carbon petroleum hydrocarbon fractions. The representative equivalent carbon number is used in the calculation of the solubility, Henry’s constant, organic carbon partitioning coefficient and molecular weight for the fractions. Lower equivalent carbon values result in higher solubilities and Henry’s constants, and lower molecular weights and organic carbon partitioning coefficients). The default values that are provided are thought to be conservative and/or representative for most sites. The values are the mid point of the narrower equivalent carbon ranges and an arbitrary but relatively low equivalent carbon value for the broader equivalent carbon ranges. The representative equivalent carbon values may be adjusted if the user has data on the distribution of mass in the NAPL by equivalent carbon number and/or by correlation of the calculated effective solubilities with site specific measured solubilities. The representative equivalent carbon values are input in the light yellow highlighted cells on the chemical properties worksheet.

SECTION 5

Hydrocarbon Risk Calculator–Example Results

As discussed in Section 4 of this user manual, the results of the hydrocarbon risk calculator are presented in a 12-page table. Table 4 is an example of the hydrocarbon risk calculator results for a hypothetical site where diesel fuel has been spilled. The input data for this hypothetical calculation are shown in Table 4 and include the following:

- The default ADEC soil and hydrogeologic conditions
- 18 AAC 75 Table B1 migration-to-groundwater soil screening levels for the BTEX compounds
- 18 AAC 75 Table B2 maximum allowable DRO and GRO soil screening levels. RRO concentration is set to 100 mg/kg, which is an arbitrary number representative of many old diesel spill sites.
- Aromatic and aliphatic GRO and DRO percentages from a representative diesel spill site
- PAH soil concentrations representative of a diesel spill site
- Groundwater concentrations representative of a diesel spill site

The following paragraphs give more detailed information about the structure and content of the hydrocarbon risk calculator tables. The hydrocarbon risk calculator tables shown in Table 4 should be referenced as needed while reviewing the following explanations.

The equations for all calculations are visible by selecting individual cells, and calculations are described in Appendix C. All equations in the hydrocarbon risk calculator are locked. Many calculations are updated as new data are entered into the calculator; however, **the phase-partitioning and risk calculations are only updated when the “calculate button” is clicked.**

Page 1, Model Input Values. Model input parameters, including soil and groundwater hydrocarbon concentrations and source zone soil and groundwater geologic conditions, are shown on Page 1 of the hydrocarbon risk calculator. The cells containing input values are highlighted in light yellow. Note that the input values for the soil hydrocarbon concentrations will typically be the 95 percent UCL values for the soil samples from the NAPL-contaminated source area of the site in question; hence, the calculation results may be used to conservatively assess risks associated with the soil direct contact, outdoor-air inhalation, indoor-air inhalation, and migration-to-groundwater routes. The groundwater concentrations used as input to the calculator are the highest concentration measured in a recent data set; therefore, these values are thought to be conservative. The soil and groundwater geologic characteristics (bulk density, moisture content, gradient, etc.) represent average conditions or the ADEC default conditions. In the Table 4 example calculations, the soil and groundwater site conditions input values are the ADEC default conditions used when calculating ADEC Tables B1 and B2. The BTEX concentrations are the ADEC Table B1 migration-to-groundwater values and the GRO and DRO values are the maximum allowable concentrations from Table B2. The PAH soil concentrations and all groundwater concentrations used in the example calculation are arbitrary.

Page 2, Migration-to-indoor-air Data Entry. Soil and building input parameters for the Johnson and Ettinger model are shown on Page 2 of the hydrocarbon risk calculator output. The Johnson and Ettinger soil input parameters describe the soil between the top of the source zone and the bottom of the building foundation. The soil values used in the example calculation are arbitrary. The building parameter input values are, in general, the EPA default values.

Page 3, Phase-partitioning Results. The hydrocarbon fractions or groups used to characterize the NAPL are shown in the first column; the representative equivalent-carbon number of the compound or fraction is shown in the third column; and the fractions of the DRO aromatics, DRO aliphatics, and GRO aliphatics in different equivalent-carbon groups are entered and shown in Column 4. Columns 5, 6, and 7 show the soil concentration of each compound or fraction, the fraction of the total petroleum hydrocarbon (TPH) mass represented by the compound or fraction, and the mole fraction of each compound or hydrocarbon group in the NAPL, respectively. Columns 8 and 9 display the dissolved and vapor concentrations in equilibrium with the NAPL. Columns 10 through 13 list the percentages of each hydrocarbon constituent in the dissolved, vapor, sorbed, and NAPL phases.

The example calculation clearly shows that that about 93 percent of the benzene, 97 percent of the toluene, and more than 98 percent of all the other hydrocarbon fractions are present in the NAPL and not in the dissolved, vapor, or adsorbed phases (as is assumed in three-phase calculations performed by the existing ADEC online calculator).

General Information on Risk Calculation Results. Hydrocarbon risk calculator output Pages 4 through 10 present risk calculation results for the different exposure pathways or cumulative risk summaries. In each section (or page), the compounds or hydrocarbon fractions used to characterize fuels are listed in the left-most column. Compounds presenting non-carcinogenic risks are listed in regular font, and compounds with carcinogenic risks are listed in bold font. Note that benzene, ethylbenzene, and naphthalene are listed twice. The first listing is for the non-carcinogenic effect, and second listing is for the carcinogenic effect of these compounds.

At this time, ethylbenzene and naphthalene are only considered to present carcinogenic risk through the inhalation pathways. In output Pages 4 through 10, residential scenario risks are presented on the left side of the page and industrial scenario risks are presented on the right side of the page. Output Pages 4 through 8, for each compound or hydrocarbon fraction, list the following: the media concentration in the exposure area, the risk-based media concentration, the fraction of risk, and whether the compound or hydrocarbon fraction exceeds the risk criteria or MCL. Note that the risk-based media concentrations do not account for cumulative risk posed by multiple compounds or exposure pathways and, therefore, are not final cleanup levels. The “fraction of risk” created by the presence of each compound of interest compares the back-calculated, risk-based soil concentration to the concentration measured at the subject site:

$$\text{fraction of risk} = \text{concentration at subject site} / \text{risk-based concentration}$$

The fraction of risk results are displayed to three or more decimal places in the results for each pathway, in the “potential cumulative risk assuming all pathways complete” section and in the “cumulative risk for pathways complete at the present time” section of the HRC. The cumulative risk listed in the “site status summary” section of the HRC is rounded to one significant figure as described in the Cumulative Risk Guidance (ADEC, 2008c).

The check for regulatory compliance with human health risk criteria is made by using Excel “if-then” statements as follows: If the fraction of risk for a given compound is less than or equal to 1, then the site meets the compliance criteria for that compound and the spreadsheet displays “0.” If the fraction of risk is greater than 1, then the site does not meet regulatory criteria and the spreadsheet displays “1” as shown for residential and industrial sites, respectively.

Page 4, Soil-ingestion Risks. Column 3 displays the hydrocarbon concentration in the soils of the subject site. Columns 4 and 7 list the soil concentration for each compound or hydrocarbon fraction that would present a hazard quotient of 1 or a carcinogenic risk of 1×10^{-5} , for residential and industrial sites, respectively (the risk-based concentrations are calculated by using Equations 3 and 4 from the ADEC guidance on cleanup level calculations). Columns 5 and 8 show the fractions of the risk-based concentrations that are present in site soils for each compound or hydrocarbon fraction. Columns 6 and 9 indicate whether the existing soil concentrations are within the risk-based criteria for each compound or hydrocarbon fraction (zero in the column indicates that the ADEC compliance criteria are met, and 1 indicates that compliance criteria have not been met).

Column 4 shows that for a hypothetical residential site, compound cleanup levels based on soil-ingestion risk are about 151 mg/kg of benzene, 8,111 mg/kg of toluene, 10,139 mg/kg of ethylbenzene, and 20,278 mg/kg of xylene. Column 4 also shows that for residential sites the aromatic and aliphatic soil cleanup levels for GRO and DRO based on soil-ingestion risk are about 20,278 mg/kg of GRO aromatics, 506,944 mg/kg of GRO aliphatics, 4,056 mg/kg of DRO aromatics, and 10,139 mg/kg of DRO aliphatics. The fraction of risk calculations show that the input DRO concentration of 12,500 mg/kg is in compliance with ADEC risk criteria (given that 20 percent are aromatics). In addition, the BTEX and PAH soil concentrations used as inputs present only a fraction of the acceptable cumulative risk for the soil-ingestion route (about 37 percent of the allowable carcinogenic risk and less than 2 percent of the allowable non-carcinogenic risk). From this information, it appears that the input soil concentrations are protective of human health through the soil-ingestion route under a residential land use scenario.

Page 5, Outdoor-air Inhalation Risks. Column 3 lists the vapor concentration in the source zone soils of the subject site based on three- or four-phase partitioning (as appropriate). Columns 4 and 7 list the soil vapor concentrations for each compound or hydrocarbon fraction that would present a hazard quotient for the outdoor-air inhalation pathway of 1 or a carcinogenic risk of 1×10^{-5} , for residential and industrial sites, respectively. Columns 5 and 8 show the fractions of the risk-based concentration that exist for each compound or hydrocarbon fraction. Columns 6 and 9 indicate whether the existing concentrations are within the risk-based criteria for each compound or hydrocarbon fraction (zero in the column indicates that the ADEC compliance criteria are met, and 1 indicates that compliance criteria have not been met).

The example calculations show that for a residential site, the soil vapor concentrations for benzene, toluene, and ethylbenzene that present an outdoor-air-inhalation pathway risk are about 6.1831, 9287, and 34.511 mg/L, respectively. The calculations also show that for residential sites, the soil vapor concentrations for GRO aromatics and aliphatics and DRO aromatics and aliphatics that present an inhalation-pathway risks are about 323, 53,015, 82, and 1257 mg/L, respectively. The vapor concentrations of the hydrocarbon fractions in the example soil, as calculated by the hydrocarbon risk calculator, are several orders of magnitude lower

than the risk-based vapor concentrations, and because there is NAPL in the soil, the soil vapor concentrations will not increase significantly as the bulk soil concentration increases. Therefore, the fraction of risk calculations shows that the example soil (containing a DRO concentration of 12,500 mg/kg and a TPH soil concentration of 14,000 mg/kg) presents only a tiny fraction of the acceptable risk (~0.1 percent of the allowable carcinogenic risk and about ~0.099 percent of the allowable non-carcinogenic risk).

The zeros in Columns 6 and 9 of Page 5 show that the existing concentrations are in compliance with ADEC criteria for the individual compounds and/or compound groups. From this information, it can be concluded that the input soil concentrations are protective of human health through the outdoor-air inhalation route under a residential land use scenario. (Note in most representative calculations performed to date, fuel hydrocarbons appear to present acceptable risk through the migration-to-outdoor-air pathway.)

Page 6, Indoor-air Inhalation Risks. Indoor-air inhalation risks are calculated by using the Johnson and Ettinger equation (Johnson and Ettinger, 1991). Column 3 lists the vapor concentration in the source zone soils of the subject site based on three- or four-phase partitioning from soil, groundwater concentrations, or input soil-gas data as follows:

- If measured soil gas concentrations are collected and used as input to the model, then the measured soil gas concentrations are used in the risk calculations
- If measured soil gas concentrations are not used as input and the NAPL-contaminated soil source is entirely within the vadose zone, then the equilibrium NAPL-vapor concentrations as calculated by Solver are used in the risk calculations
- If measured soil gas concentrations are not used as input and the NAPL-contaminated soil source extends into the zone (as indicated by cell H31), then the equilibrium water-vapor concentrations calculated using the input groundwater concentrations is used in the risk calculations.

Column 4 lists the building or indoor-air vapor concentrations calculated by the Johnson and Ettinger equation. Columns 5 and 8 list the soil vapor concentrations for each compound or hydrocarbon fraction that would present a hazard quotient for the indoor-air inhalation pathway of 1 or a carcinogenic risk of 1×10^{-5} , for residential and industrial sites, respectively.

Columns 6 and 9 show the fractions of the risk-based concentration that exist for each compound or hydrocarbon group. Columns 7 and 10 indicate whether the existing concentrations are within the risk-based criteria for each compound or hydrocarbon group (zero in the column indicates that the ADEC compliance criteria are met, and 1 indicates that compliance criteria have not been met). The example results show that the ADEC soil cleanup levels for BTEX from Table B1 and maximum allowable concentrations for GRO and DRO from Table B2 present calculated human health risks within existing regulatory standards.

Page 7, Migration-to-groundwater Potential Risks. The migration-to-groundwater calculation assesses if the site soil concentrations and hydrogeologic conditions are likely to cause groundwater to exceed regulatory criteria. The migration-to-groundwater calculations take the form of risk calculations. The migration-to-groundwater risks are not included in the cumulative risk calculation. Column 3 shows the dissolved-phase equilibrium concentration that is expected in the source zone soils of the subject site based on three- or four-phase

partitioning calculations (as appropriate) and the input soil concentrations. Column 4 lists the MCLs for each hydrocarbon compound. Columns 5 and 9 list the risk-based dissolved concentrations for each compound or hydrocarbon fraction that would present a hazard quotient of 1 or a carcinogenic risk of 1×10^{-5} for the groundwater-ingestion pathway, for residential and industrial sites, respectively. (Note that some MCLs are lower than the risk-based groundwater-ingestion concentration and some risk based concentrations are lower than the MCL.) Columns 6 and 10 show the target soil moisture concentrations for each compound or hydrocarbon fraction given the DAF calculated for the site.

Columns 7 and 11 show the fractions of the risk-based concentration that exist for each compound or hydrocarbon group. The industrial site risk-based concentration and fraction of risk calculations use assumptions for industrial site exposure. Columns 8 and 12 indicate whether the existing concentrations are within the regulatory or risk-based criteria for each compound or hydrocarbon group (zero in the column indicates that the ADEC compliance criteria are met, and a 1 indicates that compliance criteria have not been met). To be consistent with Alaska Statutes and regulations (Sec. 46.03.010(b) and 18 AAC 75.345), the industrial site migration-to-groundwater check for compliance calculation uses residential risk-based concentrations rather than industrial risk-based concentrations.

Note that the BTEX, GRO, and DRO aromatics each represent a minor fraction of the moles of NAPL present in the site soils; therefore, these aromatics have much lower effective solubilities than those calculated by using the three-phase soil-screening equations. The potential risks associated with BTEX, GRO, and DRO aromatics through the migration-to-groundwater pathway are commonly lower than might be expected given the previously published risk based concentrations listed for these compounds in the ADEC regulations. Also note that the model predicts that vadose-zone DRO aromatics and aliphatics generally will not present significant migration-to-groundwater risks because the Raoult's Law solubilities of these compounds are below the risk-based concentration multiplied by the DAF. The results show that the input soil concentrations are unlikely to present a migration-to-groundwater risk. Finally, because some MCLs are not risk-based (for example, benzene), compliance criteria may not be met (the MCL may be exceeded) even though the site poses an acceptable potential risk.

Page 8, Groundwater-ingestion Risks. Column 3 lists the dissolved concentrations measured in the saturated source zone or directly below the vadose source zone soils of the subject site. Column 4 lists the MCLs for each hydrocarbon compound. Columns 5 and 9 list the dissolved concentrations for each compound or hydrocarbon fraction that would present a groundwater ingestion pathway hazard quotient of 1 or a carcinogenic risk of 1×10^{-5} , for residential and industrial sites, respectively. Note that some MCLs are lower than the risk-based groundwater-ingestion concentration and some risk based concentrations are lower than the corresponding MCL).

Columns 6 and 10 show the groundwater compliance concentration, which is the MCL or risk-based concentration, for sites with potable groundwater. Columns 7 and 11 show the fractions of the risk-based concentration that exist for each compound or hydrocarbon group. (The MCL is not used in the fraction of risk calculation.) The industrial site risk-based concentration and fraction of risk calculations use the ADEC default industrial site exposure assumptions.

Columns 8 and 12 indicate whether the existing concentrations are within the regulatory or risk-based criteria for each compound or hydrocarbon group (zero in the column indicates that the

ADEC compliance criteria are met, and 1 indicates that compliance criteria have not been met). Note that some compliance criteria are not risk-based, for example, the MCL for benzene is 5 micrograms per liter [$\mu\text{g}/\text{L}$], and the concentration that presents an unacceptable risk is about 15 $\mu\text{g}/\text{L}$. Because some MCLs are not risk-based, compliance criteria may not be met (the MCL may be exceeded) even though the site poses an acceptable risk. In addition, to be consistent with Alaska Statutes and regulations (Sec. 46.03.010(b) and 18 AAC 75.345), the industrial site groundwater-ingestion check for compliance calculations uses residential risk-based concentrations rather than industrial risk-based concentrations. The example results show that the input water concentrations meet the regulatory standards for groundwater and also meet risk-based criteria.

Page 9, Potential Cumulative Risk Assuming All Pathways Complete. The “potential cumulative risk assuming all pathways complete” is the risk that would be present if the site was developed so that all exposure pathways were complete. For this scenario to occur, a structure (the family home or work place building) would have to be located over the contaminated soil in such a way that the indoor air route is completed, the homes (or work place) drinking water would be from a well completed in the mixing zone at the downgradient edge of the source area, residents (or site workers) would have direct contact with the contaminated source area soils in the yard, and while outside, residents (or site workers) would breath outdoor air affected by the site contaminants. This baseline scenario must be assessed for all sites. Cleanup decisions based on determinations that some exposure pathways are incomplete require ADEC approval and may trigger a need for institutional controls.

Under a risk-based corrective action/risk-based cleanup system, the potential cumulative risk must not exceed an excess carcinogenic risk of 1×10^{-5} and the cumulative hazard quotient must not exceed 1 for a site to be closed. Also note that the calculation of potential risks associated with the migration-to-indoor-air route requires some assumptions about the buildings that may be built at the site. The hydrocarbon risk calculator presents a conservative assessment of this pathway; however, different assumptions may be developed during a Method 4 risk assessment.

According to ADEC guidance, the cumulative risk is calculated as the sum of the BTEX, PAH and other individual COPC risks for the soil direct contact, outdoor air inhalation, vapor intrusion and groundwater ingestion pathways (the migration-to-groundwater risks are not included in the cumulative risk calculation). The risks associated with the GRO, DRO, and RRO compound groups are not included in the cumulative risk because the ADEC considers that the risk associated with these compounds is represented by the BTEX and PAH data; hence, the GRO, DRO, and RRO cumulative risk is not displayed.

When using a four-phase solution (when NAPL is present), the risk associated with the outdoor-air inhalation, indoor-air inhalation, and migration-to-groundwater pathways does not increase linearly with increasing concentrations. Rather, in calculations performed for other projects, the outdoor-air inhalation, indoor-air inhalation, and migration-to-groundwater risks increase only slightly when the soil concentration is doubled and tripled. It should also be noted that soil-ingestion risks do increase linearly with increasing soil concentrations and that the groundwater-ingestion risks increase linearly with increasing dissolved-phase concentrations.

The example calculation, which uses the default BTEX soil cleanup levels from ADEC Table B1 and the maximum allowable GRO and DRO concentrations from Table B2, shows that the

cumulative risk posed by the input soil and groundwater concentrations are within acceptable carcinogenic and non-carcinogenic risk levels. In accordance with ADEC guidance, the cumulative risk is the sum of the BTEX, PAH and other individual COPC risks through all exposure pathways (that is, GRO and DRO are not included in the cumulative risk calculations).

Page 10, Potential Cumulative Risk for Pathways Complete at Present Time. The “cumulative risk for the pathways complete at present time” is the risk that is present from completed exposure pathways under the current land use at the time the report is prepared. The evaluation of which exposure pathways are complete is done as part of the site characterization/site investigation work and is input to the model on Page 1 (gold block of cells). The hydrocarbon risk calculator simply sums the risk from the completed exposure pathways. For example if a residence has contaminated soil from a heating oil tank in the backyard and under the foundation of the house, but the residence is on city water system the migration-to-indoor-air, migration-to-outdoor-air, and soil-ingestion routes would likely be considered complete, but the groundwater-ingestion route would not be complete. The hydrocarbon risk calculator would sum the risk from the complete pathways and assess whether the current situation presents an acceptable or unacceptable risk.

If the current site conditions present an unacceptable risk, the responsible party and regulatory agency may use the hydrocarbon risk calculator data to establish corrective action priorities at the site and to identify the compounds and exposure routes that drive the risk. The calculation of existing cumulative risk is used primarily as a tool to allow the identification and mitigation of existing human health risk. As per ADEC guidance on cumulative risk, the cumulative risk at the present time is calculated as the sum of the BTEX, PAH and other individual COPC risks for completed pathways. The risks associated with the GRO, DRO, and RRO compound groups are not included in the existing cumulative risk because the ADEC considers that the risk associated with these compounds is represented by the BTEX and PAH data.

In the example calculation, the vapor intrusion and groundwater-ingestion pathways are not complete. Hence, the fraction of risk values for all compounds in the indoor air and groundwater-ingestion columns are zero. The example calculation shows that the cumulative risk, posed by the exposure pathways complete at the present time, are within acceptable carcinogenic and non-carcinogenic risk levels.

Page 11, Partitioning into Surface Water and Groundwater. This section of the hydrocarbon risk calculator assesses whether contaminated soil from the site has the potential to cause groundwater to exceed MCLs or risk-based concentrations or to cause surface water to exceed the ambient water quality criteria if the contaminated soil is used as fill material at an offsite location. To make these assessments, the dissolved-phase equilibrium concentration or the measured groundwater concentration (depending on whether the source is in the vadose or saturated zones) is compared to the MCL or risk-based groundwater concentrations and ambient water quality criteria. The assessment assumes a DAF of 3.3 when soil is used as vadose zone fill and a DAF of 1 when soil is used as saturated zone fill or as fill in surface water bodies.

In the example calculation, the soil from the subject site could be used as vadose zone fill at another location, assuming that the default DAF applied at the new location (as indicated by the zeros in the “check for vadose zone fill” column), but the soil should not be used as saturated zone fill (as indicated by the values of 1 in the “check for saturated zone fill” column). The soils

from the subject site should not be used as fill in a surface water body or in the saturated zone where surface waters may be affected because the soils would likely cause the surface water to exceed the criteria for benzene, total aromatic hydrocarbon, total aqueous hydrocarbon, and surface water sheen, as indicated by the values of 1 in the “check for surface water body fill” column.

Page 12, Site Status Summary. The twelfth and final section of the hydrocarbon risk calculator summarizes the site status based on the written regulations and describes limitations on the offsite transport of the contaminated soil. In section 12 risk based criteria are displayed several ways: the cumulative carcinogenic and non-carcinogenic risks are rounded to one significant figure (as described in the Cumulative Risk Guidance, ADEC, 2008c); the number of individual compounds exceeding their soil direct contact risk based concentrations and the number of individual compounds exceeding their risk based groundwater ingestion risk based concentrations are displayed; and the number of GRO, DRO and RRO aromatic and aliphatic fractions exceeding their soil direct contact, outdoor air inhalation, vapor intrusion and groundwater ingestion risk based concentrations are displayed. The HRC assesses ultimate compliance with ADEC risk criteria by assessing: if the rounded cumulative risk meets the risk standard; if each compound is less than or equal to its soil direct contact risk based concentration; if each compound is less than or equal its groundwater ingestion risk based concentration; and if the GRO, DRO and RRO fractions are less than or equal to the aromatic and aliphatic risk based concentrations for the soil direct contact, outdoor air inhalation, vapor intrusion and groundwater ingestion exposure pathways.

The summary for the hypothetical example calculation (which uses Table B1 BTEX concentrations and Table B2 maximum allowable GRO and DRO concentrations as input) shows that the hypothetical site meets the cumulative carcinogenic and non-carcinogenic risk criteria, and meets the GRO, DRO, and RRO aromatic and aliphatic risk criteria for each exposure pathway. The calculator indicates that because the human health risk criteria have been met, the site can be closed, provided the ecological risk criteria have been met. Final site closure decisions may be subject to other considerations that are not evaluated in the calculator; however, these calculations may be used as a basis for approving site management decisions. Site closure considerations not addressed in the calculator, such as free product recovery and the cleanup of stained soils to the extent practicable, maximum allowable concentration criteria, compliance with non-risk based groundwater criteria, should be addressed in the site characterization report. In addition, the calculator indicates that soils from the subject site may be used as vadose zone fill at another location, but should not be used as saturated zone fill or as fill in a surface water body. To move the contaminated soil off site the RP must apply for and receive approval from the ADEC.

If total DRO in groundwater exceeds the Method 2 cleanup levels, and if a significant portion of total DRO consists of compounds that are not characterized as aromatic or aliphatic fractions, the calculator presents this additional information as printed text. Human health risks are still calculated but site closure and risk management decisions may depend on other factors such as secondary water quality criteria. These situations are presented in the summary. Notes to the left of the page 12 printout provide additional information on the evaluation of site closure, limitations on off-site transport of impacted soils, and the possible presence of polar compounds.

SECTION 6

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TABLE 1

Selected Hydrocarbon Solubilities, Henry's Constant, K_{oc} and C_{sat} Values

Hydrocarbon Risk Calculator User Manual

Fraction	Equivalent Carbon Number	Molecular Weight	Single Component Solubility (mg/L)	H' Henry's Constant (unitless)	K_{oc} (mL/g)	Mass in Solution (mg/kg dry soil)	Mass in Vapor (mg/kg dry soil)	Mass Adsorbed (mg/kg dry soil)	Vadose Zone C_{sat} (mg/kg)	% Mass in Solution (vadose zone)	% Mass in Vapor (vadose zone)	% Mass Adsorbed (vadose zone)	Saturated Zone C_{sat} (mg/kg)
Aromatics													
Benzene	6.50	78	1750	2.28E-01	5.89E+01	350.0	35.6	103.1	489	71.62%	7.29%	21.09%	609
Toluene	7.58	92	526	2.72E-01	1.82E+02	105.2	12.8	95.7	214	49.23%	5.98%	44.80%	248
Ethylbenzene	8.50	106	169	3.23E-01	2.78E+02	33.8	4.9	47.0	86	39.46%	5.69%	54.85%	96
Xylene	8.63	106	161	2.13E-01	3.63E+02	32.2	3.1	58.4	94	34.36%	3.27%	62.37%	105
C_9	9.00	114	65	4.27E-01	1.58E+03	12.9	2.5	102.3	118	10.97%	2.09%	86.94%	121
C_{10}	10.00	122	40	2.51E-01	2.00E+03	8.0	0.9	79.4	88	9.02%	1.01%	89.97%	91
C_{12}	12.00	138	15	8.71E-02	3.16E+03	3.0	0.1	47.9	51	5.93%	0.23%	93.83%	52
C_{14}	14.00	152	5.8	3.02E-02	5.01E+03	1.2	0.0	28.8	30	3.84%	0.05%	96.11%	31
C_{16}	16.00	166	2.2	1.05E-02	7.94E+03	0.4	0.0	17.4	18	2.46%	0.01%	97.53%	18
Aliphatics													
C_6	6.00	88	16	5.25E+01	1.35E+03	3.2	74.3	21.4	99	3.21%	75.16%	21.63%	26
C_6 - C_8	7.00	102	4.5	5.50E+01	3.80E+03	0.9	21.9	17.0	40	2.24%	55.08%	42.67%	18
C_8 - C_{10}	9.00	130	0.35	6.03E+01	3.02E+04	0.1	1.9	10.7	13	0.56%	15.04%	84.40%	11
C_{10}	10.00	145	0.10	6.31E+01	85113.80	0.0	0.6	8.5	9	0.22%	6.20%	93.58%	9
C_{12}	12.00	172	0.007943	6.92E+01	6.76E+05	0.0	0.0	5.4	5	0.03%	0.91%	99.07%	5
C_{14}	14.00	200	0.000631	7.59E+01	5.37E+06	0.0	0.0	3.4	3	0.00%	0.13%	99.87%	3
C_{16}	16.00	228	0.000050	8.32E+01	4.27E+07	0.0	0.0	2.1	2	0.00%	0.02%	99.98%	2
C_{20}	20.00	283	0.0000003	1.00E+02	2.69E+09	0.0	0.0	0.9	1	0.00%	0.00%	100.00%	1
Vadose Soil Conditions:													
porosity (n)= 0.434				f_{oc} = 0.001				n_a = 0.13		sp.G.= 2.65			
bulk density (g/cm ³) = 1.5				grav. soil moist.= 0.20				n_w = 0.300		satutrated gravimetric moisture content= 0.28930818			
Saturated Soil Conditions:													
porosity (n)= 0.434				f_{oc} = 0.001				n_a = 0.00					
bulk density (g/cm ³) = 1.5								n_w = 0.43					

$$C_{sat}=(S*nw/pb) + (S*H'*na/pb) + (f_{oc} *k_{oc} *S)$$

TABLE 2

Example Dissolved BTEX Concentrations Based on COTU Fuel Analysis and Three- and Four-Phase Partitioning

Hydrocarbon Risk Calculator User Manual

Compound	Benzene	Toluene	Ethylbenzene	Xylene
Mass Fraction in COTU Arctic Diesel	0.0106	0.27	0.32	1.70
Theoretical/ Maximum Solubility (mg/L)	1750	526	169	161
3-Phase Dissolved Concentration in Soil with 5,000 mg/kg COTU Diesel (mg/L)	1.88	33.04	32.11	50.57
3-Phase Dissolved Concentration in Soil with 10,000 mg/kg COTU Diesel (mg/L)	3.76	66.09	64.22	101.14
3-Phase Dissolved Concentration in Soil with 15,000 mg/kg COTU Diesel (mg/L)	5.64	99.13	96.33	151.71
4-Phase Dissolved Concentration in Soil with 5,000 mg/kg COTU Diesel (mg/L)	0.32	2.13	0.72	3.66
4-Phase Dissolved Concentration in Soil with 10,000 mg/kg COTU Diesel (mg/L)	0.33	2.17	0.73	3.67
4-Phase Dissolved Concentration in Soil with 15,000 mg/kg COTU Diesel (mg/L)	0.33	2.18	0.76	3.68

COTU = crude oil topping unit

All soil characteristics match ADEC default assumptions

COTU March sample used in calculations

Overestimate of Dissolved Phase Concentration When Using 3-Phase Model

3-Phase Model Overestimate of Dissolved Concentration	Benzene	Toluene	Ethylbenzene	Xylene
5,000 mg/kg	595%	1551%	4447%	1382%
10,000 mg/kg	1147%	3051%	8857%	2755%
15,000 mg/kg	1708%	4547%	12642%	4123%

TABLE 3

Summary of Hydrocarbon Risk Calculator Input Parameters

Hydrocarbon Risk Calculator User Manual

Page 1 Hydrocarbon Concentrations and Soil and Groundwater Condition Variables	Recommended Test Method	Input Units	Common Minimum Value	Common Maximum Value	Default Value	Notes, Primary Source of Data, and/or Optional Source of Data
BTEX soil concentrations	8021 or 8260	mg/kg	0.001	100		site-specific data, 95% UCL or max from source area samples
GRO soil concentrations	AK 101	mg/kg	1	20000		site-specific data, 95% UCL or max from source area samples
DRO soil concentrations	AK 102	mg/kg	5	50000		site-specific data, 95% UCL or max from source area samples
RRO soil concentrations	AK 103	mg/kg	10	75000		site-specific data, 95% UCL or max from source area samples
GRO aromatic fraction	Northwest VPH	fraction	0.05	0.5		site-specific data or estimate from SOC papers
DRO aromatic fraction	Northwest EPH	fraction	0.05	0.3		site-specific data or estimate from SOC papers
RRO aromatic fraction	Northwest EPH	fraction	0.05	0.2		site-specific data or estimate from SOC papers
PAH soil concentrations	8270 sim	mg/kg	0.0001	10		site-specific data, 95% UCL or max from source area samples
BTEX dissolved concentrations	8021 or 8260	mg/L	0.0001	100		site-specific data
GRO dissolved concentrations	AK 101	mg/L	0.01	300		site-specific data; solubility limit <-300 mg/L
DRO dissolved concentrations	AK 102	mg/L	0.1	5		site-specific data; solubility limit ~5 mg/L
RRO dissolved concentrations	AK 103	mg/L	0.1	1		site-specific data; solubility limit ~1 mg/L
GRO aromatic dissolved concentration	Northwest VPH	mg/L				site-specific data; solubility limit <-300 mg/L
GRO aliphatic dissolved concentration	Northwest VPH	mg/L				site-specific data; solubility limit <-50 mg/L
DRO aromatic dissolved concentration	Northwest EPH	mg/L				site-specific data; solubility limit <-5 mg/L
DRO aliphatic dissolved concentration	Northwest EPH	mg/L				site-specific data; solubility limit <-1 mg/L
PAH dissolved concentrations	8270 sim	mg/L				site-specific data; solubility limit <-1 mg/L
contaminated soil bulk density	ASTM D-2937	lbs/ft ³	85	135	93.6	
specific gravity of solids	ASTM D-854	dimensionless	2.4	2.8	2.65	
soil moisture content	ASTM D-2216	% of solids weight	1	40	10	
fraction of organic carbon	EPA 415.1 or SW-846 Method 9060	fraction	0.001	0.1	0.001	site-specific soil sample data from uncontaminated portion of the site but in same strata as is contaminated
soil temp C°		C°	-5	15	25	site-specific data, water temp while purging or thermistor reading in soil column, or climate atlas
source length		ft	5	1000	105	site-specific from map of the NAPL contaminated soil source area, measured in direction of groundwater flow
average precipitation		in/yr	10	200	25.59 for <40"/yr zone; 118.11 for >40"/yr zone	National Weather Service records
hydraulic gradient		dimensionless (ft/ft)	0.0001	0.01	0.002	site-specific groundwater contour map
aquifer hydraulic conductivity (cm/sec)		cm/sec	0.0000001	0.01	0.00278	site-specific slug test; pump test; calculated based on grain size; estimated based on soil texture
aquifer thickness (ft)		ft				drilling logs from the site; USGS or ADOT etc. drilling records from area; estimated from geomorphology; geophysical methods
biodegradation half life	Bioscreen	days	3	10,000		The half life describes the time required for half of the dissolved phase mass to biodegrade. Half life values are best determined on a site specific basis from data on the change in dissolved concentration downgradient of the source area. Alternatively, literature values may be used. Half life values vary between compounds, most fuel hydrocarbon tend to degrade relatively readily, but PCBs and chlorinated compounds tend to be recalcitrant (degrade slowly)

TABLE 3

Summary of Hydrocarbon Risk Calculator Input Parameters

Hydrocarbon Risk Calculator User Manual

Page 1 Hydrocarbon Concentrations and Soil and Groundwater Condition Variables	Recommended Test Method	Input Units	Common Minimum Value	Common Maximum Value	Default Value	Notes, Primary Source of Data, and/or Optional Source of Data
nonpotable aquifer?			1	10	1	if aquifer is nonpotable then groundwater ingestion risk is not included in the cumulative risk; to be listed as nonpotable, ADEC must have designated the water as nonpotable according to 18 AAC 75.345
Exposure Routes Complete at Present Time:						
Soil Ingestion		dimensionless	0	1		site conceptual model
Outdoor Air		dimensionless	0	1		site conceptual model
Indoor Air		dimensionless	0	1		site conceptual model
Groundwater Ingestion		dimensionless	0	1		site conceptual model
Climate Zone	climate atlas	dimensionless			1, 2 or 3	enter "1" for an arctic site; "2" for the <40" precip zone; and "3" for the >40" precip zone
depth to groundwater at seasonal low water level at downgradient end of source (ft)		feet	3	200+		site investigation
seasonal water table fluctuation (ft)		feet	1	15+		site investigation
depth to bottom of source zone at downgradient edge of source (ft)		feet	1	50+		site investigation
depth to top of area wide source zone at downgradient edge of source (ft; should equal J&E model sum of cells C61 to E61 unless soil gas data is used)		feet	0	100+		site investigation
Page 2 Johnson & Ettinger Model Variables	Recommended Test Method	Input Units	Common Minimum	Common Maximum	Default Value	Notes, Primary Source of Data and/or Optional Source of Data
uncontaminated soil bulk density	ASTM D-2937	lbs/ft ³	85	135	93.6	site soil sample testing
specific gravity of solids	ASTM D-854	dimensionless	2.4	2.8	2.65	site soil sample testing
soil moisture content	ASTM D-2216	% of solids weight	1	40	10	site soil sample testing
fraction of organic carbon	EPA 415.1 or SW-846 Method 9060	fraction	0.001	0.1	0.001	site soil sample testing
layer thickness (ft)		ft	0.1	20		site boring logs
kv = soil vapor permeability (cm ²)		cm ²			1.00E-08	
Lb = length of building (cm)		cm			1000	site measurement or default residence value
Wb = width of building (cm)		cm			1000	site measurement or default residence value
Hb = height of building (cm)		cm			366 for building with basements; 244 for slab on grade foundations	site measurement or default residence value
ER = air exchange rate (1/hr)		exchanges per hour			0.25	site measurement or default residence value
Lf = depth below grade of bottom of floor slab or basement (cm)		cm			200 for building with basements; 15 for slab on grade foundations	site measurement or default residence value
Wcrack = floor -wall seam crack width (cm)		cm			0.1	site measurement or default residence value
Lcrack = enclosed space foundation thickness or slab thickness (cm)		cm			10	site measurement or default residence value
delta P = pressure differential between building and soil (g/cm-s ²)		g/cm-s ²	0	200	40	site measurement or default residence value

TABLE 3

Summary of Hydrocarbon Risk Calculator Input Parameters

Hydrocarbon Risk Calculator User Manual

Page 3 Hydrocarbon Character Variables	Recommended Test Method	Input Units	Common Minimum Value	Common Maximum Value	Default Value	Notes, Primary Source of Data, and/or Optional Source of Data
Aromatic C ₁₀ -C ₁₂	Northwest EPH	dimensionless or (gm/gm)	0	1	0 is minimum value; 1 is maximum value; typical fresh arctic diesel is ~0.2	Fraction of the DRO aromatic mass within the C10 to C12 equivalent carbon range; sum of DRO aromatic mass fractions must equal 1.0000. Site-specific data or fresh fuel characterization from SOC papers.
Aromatic C ₁₂ -C ₁₆	Northwest EPH	dimensionless or (gm/gm)	0	1	0 is minimum value; 1 is maximum value; typical fresh arctic diesel is ~0.62	Fraction of the DRO aromatic mass within the C12 to C16 equivalent carbon range; sum of DRO aromatic mass fractions must equal 1.0000. Site-specific data or fresh fuel characterization from SOC papers.
Aromatic C ₁₆ -C ₂₄	Northwest EPH	dimensionless or (gm/gm)	0	1	0 is minimum value; 1 is maximum value; typical fresh arctic diesel is ~0.18	Fraction of the DRO aromatic mass within the C16 to C21 equivalent carbon range; sum of DRO aromatic mass fractions must equal 1.0000. Site-specific data or fresh fuel characterization from SOC papers.
Aliphatic C ₅ -C ₆	Northwest VPH	dimensionless or (gm/gm)	0	1	0 is minimum value; 1 is maximum value; typical fresh gasoline is ~0.5	Fraction of the GRO aliphatic mass within the C5 to C6 equivalent carbon range; sum of GRO aliphatic mass fractions must equal 1.0000. Site-specific data or fresh fuel characterization from SOC papers.
Aliphatic C ₆ -C ₈	Northwest VPH	dimensionless or (gm/gm)	0	1	0 is minimum value; 1 is maximum value; typical fresh gasoline is ~0.2	Fraction of the GRO aliphatic mass within the C6 to C8 equivalent carbon range; sum of GRO aliphatic mass fractions must equal 1.0000. Site-specific data or fresh fuel characterization from SOC papers.
Aliphatic C ₈ -C ₁₀	Northwest VPH	dimensionless or (gm/gm)	0	1	0 is minimum value; 1 is maximum value; typical fresh gasoline is ~0.3	Fraction of the GRO aliphatic mass within the C8 to C10 equivalent carbon range; sum of GRO aliphatic mass fractions must equal 1.0000. Site-specific data or fresh fuel characterization from SOC papers.
Aliphatic C ₁₀ -C ₁₂	Northwest EPH	dimensionless or (gm/gm)	0	1	0 is minimum value; 1 is maximum value; typical fresh arctic diesel is ~0.39	Fraction of the DRO aliphatic mass within the C10 to C12 equivalent carbon range; sum of DRO aliphatic mass fractions must equal 1.0000. Site-specific data or fresh fuel characterization from SOC papers.
Aliphatic C ₁₂ -C ₁₆	Northwest EPH	dimensionless or (gm/gm)	0	1	0 is minimum value; 1 is maximum value; typical fresh arctic diesel is ~0.53	Fraction of the DRO aliphatic mass within the C12 to C16 equivalent carbon range; sum of DRO aliphatic mass fractions must equal 1.0000. Site-specific data or fresh fuel characterization from SOC papers.
Aliphatic C ₁₆ -C ₂₁	Northwest EPH	dimensionless or (gm/gm)	0	1	0 is minimum value; 1 is maximum value; typical fresh arctic diesel is ~0.08	Fraction of the DRO aliphatic mass within the C16 to C21 equivalent carbon range; sum of DRO aliphatic mass fractions must equal 1.0000. Site-specific data or fresh fuel characterization from SOC papers.

Table 4		Migration to Indoor Air-- Data Entry			Tank 117 Example			Remote Site, Alaska				
Page 2		NAPL source area soil gas concentrations or measured soil gas concentrations used as input. Attenuation factor "alpha" calculated by the Johnson & Ettinger model following the EPA advanced soil gas solution to the J & E model. Incremental risk posed by NAPL source area soil gas concentrations via the migration to indoor air pathway shown in section 6 below and entered into the cumulative risk calculations.										
Site Specific and/or Field Data in Yellow Highlighted Cells												
Soil Properties:	Upper most uncontaminated soil layer immediately below slab	Middle Layer (not contaminated)	Bottom Layer (not contaminated)	Building Properties:	input value	default input values: basement	default input values: slab on grade			Human Health Exposure Criteria		
bulk density (lbs/ft ³)	94.00	100.00	105.00	Lb = length of building (cm)	1000	1000	1000	L _T = total source-building separation distance (cm)	122	Residential	Industrial	
bulk density (g/cm ³)	1.51	1.6026	1.682692308	Wb = width of building (cm)	1000	1000	1000	Acrack= area of total cracks (cm ²) = Xcrack ² Wcrack = Ab/h	400	Target Carcinogenic Risk (TRC, default = 10 ⁻⁵)	1.00E-05	1.00E-05
specific gravity of solids	2.65	2.65	2.65	Hb = height of building (cm)	366	366	244	Xcrack = floor-wall seam perimeter (cm)	4000	THQ= target hazard quotient (default = 1.0)	1	1
porosity	0.43	0.40	0.37	ER = air exchange rate (1/h)	0.25	0.25		u = viscosity of air (g/cm-sec)	1.75E-04	ATc= averaging time carcinogen (days), (=70 years)	25,550	25,550
moisture content (% by weight)	6.000	12.000	18.000	Lf = depth below grade of bottom of floor slab or basement (cm)	183	200	15	Zcrack = crack depth below grade (cm)	182.8822238	ATnc= averaging time non-carcinogen	30	30
foc	0.001	0.001	0.001	Lf = depth below grade of bottom of floor slab or basement (ft)	6	6.5616	0.49212	equation 16 r crack= n/(Ab/Xcrack)	1.00E-01	ED= exposure duration (30 years)	30	25
water filled porosity	0.090	0.192307692	0.302884615	Lcrack = enclosed space foundation thickness or slab thickness (cm)	10	10	10	n = Acrack/Ab (0<n<=1)	2.31E-04	EF= effective exposure frequency (350 days/year)	350	100
air filled porosity	0.341	0.203	0.062	delta P = pressure differential between building and soil (g/cm-s ²)	40	40 g/cm-s ² = 4 pascals (Pa)	typical conservative values = 4 or 5 Pa; max range = 0 to 20 Pa	equation 14 Q building=building ventilation rate (cm ³ /sec) = (Lb*Wb*Hb*ER)/3.600s/h	2.54E+04	Industrial Scenario Exposure Frequency input values	days per week	6
Thickness of uncontaminated soil layers above source (ft: upper most layer must extend below the depth of foundation)	7	2	1	kv = soil vapor permeability= top soil layer (cm ²)	2.71E-09	1.00E-08		equation 14 Q building=building ventilation rate (cm ³ /sec; if a value is input it will be used in the alpha calculation--optional)		hours per day		8
layer thickness (cm)	213.36	60.96	30.48	Ag= surface area of enclosed space below grade (cm ²)	1.73E+06	=area of basement walls+ basement floor... or area of slab		equation 15 Q soil = (2* pi * delta P * kv * Xcrack)/u ln (2 Zcrack / r crack)	1.90E+00	weeks per year		50
contaminant or to soil gas sample if soil gas data used as input to model	10	Ls (cm)	304.80	Q building=building ventilation rate (cm ³ /sec)	2.54E+04			Rc (gas constant, cal/mol-degree K)	1.9872	C cancer =	[(TCR*ATc)/(EF*ED*U RF)]	
kv = soil vapor permeability (cm ² ; est values in cells Q65 to S65)	2.71E-09	2.05E-09	6.68E-10	Wcrack = floor-wall seam crack width (cm)	0.1			R (gas constant, atm-m ³ /mol-degree K)	8.2057E-05	C non-cancer =	(TOH'R/c*1000ug/mg)	

Table 4		Phase Partitioning Results			Tank 117 Example			Remote Site, Alaska						
Page 3	column 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Hydrocarbon Fractions		Median Equivalent Carbon	Distribution of DRO & GRO into Aromatic & Aliphatic Equivalent Carbon Ranges (varies by fuel type)	Bulk Soil Concentration (mg/kg)	Fraction of TPH Mass	Xi (Mole Fraction in NAPL using 4-phase model; unique solution)	Concentration in Soil Water (mg of chemical/L of pore water)	Concentration in Soil Gas (mg/L pore air)	% of Hydrocarbon Mass in Dissolved Phase	% of Hydrocarbon Mass in Vapor Phase	% of Hydrocarbon Mass Adsorbed to Soils	% of Hydrocarbon Mass in NAPL	Sum of Dissolved, Vapor, Adsorbed and NAPL Phases	
Benzene C ₆ -C ₇		6.50	from analysis	0.025	0.000002	3.53E-06	6.32E-03	7.31E-04	2.528%	0.502%	4.184%	92.79%	100.00%	
Toluene C ₇ -C ₈		7.58	from analysis	6.500	0.000464	8.17E-04	4.30E-01	5.41E-02	0.661%	0.143%	1.771%	97.43%	100.00%	
Ethylbenzene C ₈ -C ₉		8.50	from analysis	6.900	0.000493	7.63E-04	1.29E-01	1.76E-02	0.187%	0.044%	0.968%	98.80%	100.00%	
Xylene C ₈ -C ₉		8.63	from analysis	63.000	0.004500	7.01E-03	7.43E-01	8.44E-02	0.118%	0.023%	0.522%	99.34%	100.00%	
Aromatic C ₉ -C ₁₀		9.50	from analysis	203.575	0.014541	2.03E-02	1.03E+00	1.36E-01	0.050%	0.012%	0.897%	99.04%	100.00%	
Aromatic C ₁₀ -C ₁₂		11.00	0.24430	610.759	0.043626	5.55E-02	1.36E+00	6.46E-02	0.022%	0.002%	0.560%	99.42%	100.00%	
Aromatic C ₁₂ -C ₁₆		13.00	0.55682	1392.057	0.099433	1.14E-01	1.06E+00	2.41E-02	0.008%	0.000%	0.304%	99.69%	100.00%	
Aromatic C ₁₆ -C ₂₁		17.00	0.19887	497.183	0.035513	3.42E-02	4.61E-02	2.79E-04	0.001%	0.000%	0.093%	99.91%	100.00%	
Aromatic C ₂₁ -C ₃₅		25.00	1.0000	20.000	0.001429	1.07E-03	3.02E-05	1.01E-08	0.000%	0.000%	0.010%	99.99%	100.00%	
Aliphatic C ₅ -C ₆		5.50	0.00000	0.000	0.000000	0.00E+00	0.00E+00	0.00E+00	0.000%	0.000%	0.000%	0.00%	0.00%	
Aliphatic C ₇ -C ₈		7.00	0.00227	2.539	0.000181	2.94E-04	1.58E-03	3.97E-02	0.006%	0.269%	0.236%	99.49%	100.00%	
Aliphatic C ₉ -C ₁₀		9.00	0.99773	1117.461	0.079819	1.02E-01	4.34E-02	1.40E+00	0.000%	0.022%	0.117%	99.86%	100.00%	
Aliphatic C ₁₀ -C ₁₂		11.00	0.34521	3452.123	0.246580	2.59E-01	8.77E-03	3.67E-01	0.000%	0.002%	0.061%	99.94%	100.00%	
Aliphatic C ₁₂ -C ₁₆		13.00	0.55788	5578.849	0.398489	3.56E-01	9.57E-04	9.70E-02	0.000%	0.000%	0.033%	99.97%	100.00%	
Aliphatic C ₁₆ -C ₂₁		17.00	0.09690	969.028	0.069216	4.76E-02	8.09E-07	5.44E-04	0.000%	0.000%	0.010%	99.99%	100.00%	
Aliphatic C ₂₁ -C ₃₅		25.00	1.0000	80.000	0.005714	2.71E-03	1.83E-12	4.04E-08	0.000%	0.000%	0.001%	100.00%	100.00%	
				14000.000	100.0000%	1.00000	4.86E+00	2.29E+00						

sum of GRO aromatic mass fractions must equal 1 1.000000E+00 1400.000 sum of GRO concentrations should equal input GRO concentration

sum of GRO aliphatic mass fractions must equal 1 1.000000E+00 12500.000 sum of DRO concentrations must equal input DRO concentration

sum of DRO aromatic mass fractions must equal 1 1.000000E+00 100.000 sum of RRO concentrations must equal input RRO concentration

sum of DRO aliphatic mass fractions must equal 1 1.000000E+00

Table 4		Migration to Outdoor Air Vapor Inhalation Risks						
Page 5		Tank 117 Example				Remote Site, Alaska		
1	2	3	4	5	6	7	8	9
Compounds		Vapor Concentration in Sample (based on 3 or 4- phase partitioning, whichever is accurate, mg/L)	Residential Site Hypothetical Soil Vapor Concentration when HQ=1 or Target Risk =10 ⁻⁵ (mg/L; from 3-phase equation)	Fraction of Risk Based Target Concentration (values greater than 1 exceed the risk based target)	Check for compliance with risk levels (0= in compliance; 1= not in compliance)	Industrial Site Hypothetical Soil Vapor Concentration when HQ=1 or Target Risk =10 ⁻⁵ (mg/L; from 3-phase equation)	Fraction of Risk Based Target Concentration (values greater than 1 exceed the risk based target)	Check for compliance with risk levels (0= in compliance; 1= not in compliance)
Benzene (c & nc)	nc	7.31E-04	62.0076	1.18E-05	0	183.	3.98E-06	0
Toluene (nc)	nc	0.0541	9,287.	5.82E-06	0	27,469.	1.97E-06	0
Ethylbenzene (c & nc)	nc	0.0176	1,627.	1.08E-05	0	4,812.	3.67E-06	0
Xylenes (total) (nc)	nc	0.0844	162.	5.20E-04	0	480.	1.76E-04	0
GRO Aromatics (nc)	nc	0.1362	323.	4.22E-04	0	955.	1.43E-04	0
DRO Aromatics (nc)	nc	0.0891	82,2826	0.0011	0	243.	3.66E-04	0
RRO Aromatics (nc)	nc	1.01E-08	No RIC	0.00E+00	0	No RIC	0.00E+00	0
GRO Aliphatics (nc)	nc	1.443	53,015.	2.72E-05	0	156,803.	9.20E-06	0
DRO Aliphatics (nc)	nc	0.4649	1,257.	3.70E-04	0	3,717.	1.25E-04	0
RRO Aliphatics (nc)	nc	4.04E-08	No RIC	0.00E+00	0	No RIC	0.00E+00	0
Acenaphthene (nc)	nc	6.04E-07	No RIC	0.00E+00	0	No RIC	0.00E+00	0
Acenaphthylene (nc)	nc	5.72E-07	No RIC	0.00E+00	0	No RIC	0.00E+00	0
Anthracene (nc)	nc	2.39E-09	No RIC	0.00E+00	0	No RIC	0.00E+00	0
Benzo(g,h,i)perylene (nc)	nc	1.02E-12	No RIC	0.00E+00	0	No RIC	0.00E+00	0
Fluoranthene (nc)	nc	4.83E-09	No RIC	0.00E+00	0	No RIC	0.00E+00	0
Fluorene (nc)	nc	2.01E-07	No RIC	0.00E+00	0	No RIC	0.00E+00	0
Naphthalene (c & nc)	nc	5.92E-05	0.662	8.95E-05	0	1,9581	3.03E-05	0
Phenanthrene (nc)	nc	2.03E-08	No RIC	0.00E+00	0	No RIC	0.00E+00	0
Pyrene (nc)	nc	1.45E-08	No RIC	0.00E+00	0	No RIC	0.00E+00	0
Benzene (c & nc)	c	7.31E-04	6.1831	1.18E-04	0	21,9453	3.33E-05	0
Ethylbenzene (c & nc)	c	0.0176	34,5111	5.11E-04	0	122.	1.44E-04	0
Benzo(a)anthracene (c)	c	1.28E-10	5.30E-04	2.41E-07	0	0.0019	6.79E-08	0
Benzo(b)fluoranthene (c)	c	1.79E-12	3.05E-05	5.88E-08	0	1.08E-04	1.66E-08	0
Benzo(k)fluoranthene (c)	c	2.22E-12	2.37E-04	9.38E-09	0	8.42E-04	2.64E-09	0
Benzo(a)pyrene (c)	c	1.77E-13	1.31E-06	1.35E-07	0	4.65E-06	3.81E-08	0
Chrysene (c)	c	2.50E-10	0.0361	6.93E-09	0	0.1282	1.95E-09	0
Dibenz(a,h)anthracene (c)	c	5.84E-14	5.44E-08	1.07E-06	0	1.93E-07	3.02E-07	0
Indeno(1,2,3-cd)pyrene (c)	c	3.29E-14	6.28E-06	5.24E-09	0	2.23E-05	1.48E-09	0
Naphthalene (c & nc)	c	5.92E-05	0.1514	3.91E-04	0	0.5375	1.10E-04	0
1,2,4-Trimethylbenzene (nc)	nc	5.24E-04	8,9125	5.88E-05	0	26,3604	1.99E-05	0
1-Methylnaphthalene (nc)	nc	1.38E-05	2,8339	4.86E-06	0	8,3819	1.64E-06	0
2-Methylnaphthalene (nc)	nc	1.32E-05	2,5413	5.20E-06	0	7,5164	1.76E-06	0
Chlordane (c & nc)	nc	3.72E-10	0.012	3.10E-08	0	0.0355	1.05E-08	0
	nc							
	nc							
	nc							
Chlordane (c & nc)	c	3.72E-12	0.004	9.30E-10	0	0.0142	2.62E-10	0
	c							
	c							
	c							
	c							
	c							
	c							
	c							
Carcinogenic Cumulative Risk				0.001	0		2.88E-04	0
Non-carcinogenic Cumulative Risk				7.07E-04	0		2.39E-04	0

Values shown in the fourth and seventh columns are the normalized fraction of the risk based level, and not the carcinogenic risk level. The fraction of risk multiplied by 10⁻⁵ equals the carcinogenic risk level for the carcinogenic compounds. Carcinogenic compounds shown in bold.

Table 4		Migration to Indoor Air Vapor Inhalation Risks								
Page 6		Tank 117 Example				Remote Site, Alaska				
1	2	3	4	5	6	7	8	9	10	
Compounds		Vapor Concentration in Sample (ug/m ³)	Building Vapor Concentration given site conditions (ug/m ³)	Residential Land Use Target Building Vapor Concentration when HQ=1 or Target Risk =10 ⁻⁵ (ug/m ³). Value listed depends on whether C or NC risks are being evaluated)	Residential Land Use Fraction of Risk Based Target Concentration (values greater than 1 exceed the risk based target)	Residential Land Use check for compliance with risk levels (0= in compliance, 1= not in compliance)	Industrial Land Use Target Building Vapor Concentration when HQ=1 or Target Risk =10 ⁻⁵ (ug/m ³). Value listed depends on whether C or NC risks are being evaluated)	Industrial Land Use Fraction of Risk Based Target Concentration (values greater than 1 exceed the risk based target)	Industrial Land Use check for compliance with risk levels (0= in compliance, 1= not in compliance)	
Benzene (c & nc)	nc	731.	0.0378	31.2857	0.00121	0	131.4.	2.876E-04	0	
Toluene (nc)	nc	54,061.	2.7571	5,214.	5.288E-04	0	21,900.0.	1.259E-04	0	
Ethylbenzene (c & nc)	nc	17,638.	0.8463	1,043.	8.115E-04	0	4,380.0.	1.932E-04	0	
Xylenes (total) (nc)	nc	84,352.	4.0571	104.	0.0389	0	438.0.	0.00926	0	
GRO Aromatics (nc)	nc	136,249.	7.3361	417.	0.01759	0	1,752.0.	0.00419	0	
DRO Aromatics (nc)	nc	89,065.	5.0726	209.	0.02432	0	876.0.	0.00579	0	
RRO Aromatics (nc)	nc	0.0101	7.65E-07	No RIC	0.000E+00	0	No RIC	0	0	
GRO Aliphatics (nc)	nc	1,443,000.	74.5097	19,189.	0.00388	0	80,592.0.	9.245E-04	0	
DRO Aliphatics (nc)	nc	464,871.	24.0027	1,043.	0.02302	0	4,380.0.	0.00548	0	
RRO Aliphatics (nc)	nc	0.0404	2.08E-06	No RIC	0.000E+00	0	No RIC	0	0	
Acenaphthene (nc)	nc	0.6037	4.07E-05	No RIC	0.000E+00	0	No RIC	0	0	
Acenaphthylene (nc)	nc	0.5718	3.91E-05	No RIC	0.000E+00	0	No RIC	0	0	
Anthracene (nc)	nc	0.0024	1.67E-07	No RIC	0.000E+00	0	No RIC	0	0	
Benzo(g,h,i)perylene (nc)	nc	1.02E-06	7.89E-11	No RIC	0.000E+00	0	No RIC	0	0	
Fluoranthene (nc)	nc	0.0048	3.50E-07	No RIC	0.000E+00	0	No RIC	0	0	
Fluorene (nc)	nc	0.2014	1.39E-05	No RIC	0.000E+00	0	No RIC	0	0	
Naphthalene (c & nc)	nc	59,2432	0.0037	3.1286	0.00119	0	13.14	2.834E-04	0	
Phenanthrene (nc)	nc	0.0203	1.43E-06	No RIC	0.000E+00	0	No RIC	0	0	
Pyrene (nc)	nc	0.0145	1.05E-06	No RIC	0.000E+00	0	No RIC	0	0	
Benzene (c & nc)	c	731.	0.0378	3.1197	0.01211	0	13.10256	0.00288	0	
Ethylbenzene (c & nc)	c	17,638.	0.8463	22.1212	0.03826	0	92.90909	0.00911	0	
Benzo(a)anthracene (c)	c	1.28E-04	9.38E-09	0.2765	3.394E-08	0	1.16136	8.081E-09	0	
Benzo(b)fluoranthene (c)	c	1.79E-06	1.33E-10	0.2765	4.813E-10	0	1.16136	1.146E-10	0	
Benzo(k)fluoranthene (c)	c	2.22E-06	1.65E-10	2.7652	5.983E-11	0	11.61364	1.425E-11	0	
Benzo(a)pyrene (c)	c	1.77E-07	1.40E-11	0.0277	5.073E-10	0	0.11614	1.208E-10	0	
Chrysene (c)	c	2.50E-04	1.83E-08	27.6515	6.629E-10	0	116.1.	1.578E-10	0	
Dibenz(a,h)anthracene (c)	c	5.84E-08	1.26E-11	0.0277	4.550E-10	0	0.11614	1.083E-10	0	
Indeno(1,2,3-cd)pyrene (c)	c	3.29E-08	2.50E-12	0.2765	9.046E-12	0	1.16136	2.154E-12	0	
Naphthalene (c & nc)	c	59.2432	0.0037	0.7157	0.0052	0	3.00588	0.00124	0	
1,2,4-Trimethylbenzene (nc)	nc	524.	0.0244	7.3	0.00334	0	30.66	7.958E-04	0	
1-Methylnaphthalene (nc)	nc	13.7593	8.47E-04	14.6	5.798E-05	0	61.32	1.381E-05	0	
2-Methylnaphthalene (nc)	nc	13.2167	8.34E-04	14.6	5.713E-05	0	61.32	1.360E-05	0	
Chlordane (c & nc)	nc	3.72E-04	2.45E-08	0.73	3.354E-08	0	3.066	7.985E-09	0	
	nc									
	nc									
	nc									
Chlordane (c & nc)	c	3.72E-06	2.45E-10	0.2433	1.006E-09	0	1.022	2.395E-10	0	
	c									
	c									
	c									
	c									
	c									
	c									
	c									
	c									
Carcinogenic Cumulative Risk					0.0556	0		0.0132	0	
Non-carcinogenic Cumulative Risk					0.0461	0		0.011	0	

Values shown in the fifth and eighth columns are the normalized fraction of the risk based level, and not the carcinogenic risk level. The fraction of risk multiplied by 10⁻⁵ equals the carcinogenic risk level for the carcinogenic compounds. Carcinogenic compounds shown in bold.

Table 4		Calculated Migration to Groundwater Levels									
Page 7		Tank 117 Example				Remote Site, Alaska					
1	2	3	4	5	6	7	8	9	10	11	12
Compounds	nc	Dissolved Concentration in Soil Sample (based on 3 or 4 phase partitioning, whichever is accurate, mg/l)	Maximum Contaminant Level (mg/L)	Residential Land Human Health Risk Based Drinking Water Concentration (mg/l)	Residential Land Soil Moisture Target Concentration (MCL or Risk Based Concentration Multiplied by the DAF....MCLs values used for compounds with MCLs)	FYI Hypothetical Fraction of Risk Based Target Concentration (values greater than exceed the risk based target; MCLs not used)	Check for compliance with regulatory levels (MCLs used for compounds with MCLs; 0= in compliance; 1= not in compliance)	Industrial Land Human Health Risk Based Drinking Water Concentration (mg/l)	Industrial Land Soil Moisture Target Concentration (MCL or Risk Based Concentration Multiplied by the DAF....MCLs values used for compounds with MCLs)	FYI Hypothetical Fraction of Risk Based Target Concentration (values greater than 1 exceed the risk based target; MCLs not used)	Check for compliance with regulatory levels (MCLs used for compounds with MCLs & Residential RBCs used for compounds without MCLs: 0= in compliance; 1= not in compliance)
Benzene (c & nc)	nc	0.0063	0.005	0.146	9.370E-02	0.0023	0	0.2044	9.370E-02	0.0017	0
Toluene (nc)	nc	0.4295	1.	2.92	2.138E+29	6.88E-31	0	4.088	2.138E+29	4.91E-31	0
Ethylbenzene (c & nc)	nc	0.129	0.7	3.65	1.819E+05	1.36E-07	0	5.11	1.819E+05	9.71E-08	0
Xylenes (total) (nc)	nc	0.7426	10.	7.3	8.003E+05	9.28E-07	0	10.22	1.096E+06	6.63E-07	0
GRO Aromatics (nc)	nc	1.0272		7.3	2.191E+05	4.69E-06	0	10.22	3.067E+05	3.35E-06	0
DRO Aromatics (nc)	nc	2.4691		1.46	5.571E+05	4.43E-06	0	2.044	7.800E+05	3.17E-06	0
RRO Aromatics (nc)	nc	3.02E-05		1.095	6.649E+96	4.54E-102	0	1.533	9.308E+96	3.24E-102	0
GRO Aliphatics (nc)	nc	0.0449		183.	3.336E+49	1.35E-51	0	256.	4.671E+49	9.62E-52	0
DRO Aliphatics (nc)	nc	0.0097		3.65	>1E+308	1/>1E+308	0	5.11	>1E+308	1/>1E+308	0
RRO Aliphatics (nc)	nc	1.83E-12		73.	>1E+308	1/>1E+308	0	102.	>1E+308	1/>1E+308	0
Acenaphthene (nc)	nc	3.257E-04		2.19	4.628E+02	7.04E-07	0	3.066	6.479E+02	5.03E-07	0
Acenaphthylene (nc)	nc	3.954E-04		2.19	4.628E+02	8.55E-07	0	3.066	6.479E+02	6.10E-07	0
Anthracene (nc)	nc	5.154E-06		10.95	3.301E+05	1.56E-11	0	15.33	4.622E+05	1.12E-11	0
Benzo(g,h,i)perylene (nc)	nc	8.545E-07		1.095	>1E+308	1/>1E+308	0	1.533	>1E+308	1/>1E+308	0
Fluoranthene (nc)	nc	7.644E-05		1.46	1.761E+12	4.34E-17	0	2.044	2.466E+12	3.10E-17	0
Fluorene (nc)	nc	2.078E-04		1.46	1.878E+03	1.11E-07	0	2.044	2.629E+03	7.91E-08	0
Naphthalene (c & nc)	nc	0.00992		0.73	2.724E+01	3.64E-04	0	1.022	3.814E+01	2.60E-04	0
Phenanthrene (nc)	nc	5.362E-05		10.95	3.792E+05	1.41E-10	0	15.33	5.309E+05	1.01E-10	0
Pyrene (nc)	nc	1.805E-04		1.095	7.853E+11	2.30E-16	0	1.533	1.099E+12	1.64E-16	0
Benzene (c & nc)	c	0.0063	0.005	0.0155	9.370E-02	0.0218	0	0.026	9.370E-02	0.013	0
Ethylbenzene (c & nc)	c	0.129	0.7	No Sto	1.819E+05	0.00E+00	0	No Sto	1.819E+05	0.00E+00	0
Benzo(a)anthracene (c)	c	1.924E-06	0.001	0.0012	1.523E+33	1.08E-39	0	0.002	1.523E+33	6.45E-40	0
Benzo(b)fluoranthene (c)	c	6.232E-07	0.001	0.0012	1.951E+119	2.74E-126	0	0.002	1.951E+119	1.63E-126	0
Benzo(k)fluoranthene (c)	c	1.015E-06	0.001	0.0117	7.616E+116	1.14E-124	0	0.0196	7.616E+116	6.80E-125	0
Benzo(a)pyrene (c)	c	1.158E-07	2.00E-04	1.17E-04	8.885E+115	1.30E-123	0	1.96E-04	1.493E+116	7.75E-124	0
Chrysene (c)	c	9.883E-06	0.1	0.1167	8.615E+35	9.83E-42	0	0.196	8.615E+35	5.85E-42	0
Dibenz(a,h)anthracene (c)	c	6.830E-07	1.00E-04	1.17E-04	>1E+308	1/>1E+308	0	1.96E-04	>1E+308	1/>1E+308	0
Indeno(1,2,3-cd)pyrene (c)	c	3.110E-08	0.001	0.0012	>1E+308	1/>1E+308	0	0.002	>1E+308	1/>1E+308	0
Naphthalene (c & nc)	c	0.00992		No Sto	No Sto	0.00E+00	0	No Sto	No Sto	0.00E+00	0
1,2,4-Trimethylbenzene (nc)	nc	0.00561		1.825	8.348E+01	6.72E-05	0	2.555	1.169E+02	4.80E-05	0
1-Methylnaphthalene (nc)	nc	0.00208		0.146	6.025E+01	3.45E-05	0	0.2044	8.435E+01	2.46E-05	0
2-Methylnaphthalene (nc)	nc	0.00253		0.146	5.708E+01	4.43E-05	0	0.2044	7.991E+01	3.16E-05	0
Chlordane (c & nc)	nc	1.029E-06	0.002	0.0183	9.424E-01	1.20E-07	0	0.0256	9.424E-01	8.54E-08	0
	nc										
	nc										
	nc										
Chlordane (c & nc)	c	1.029E-08	0.002	0.0024	9.424E-01	8.97E-09	0	0.0041	9.424E-01	5.34E-09	0
	c										
	c										
	c										
	c										
	c										
	c										
	c										
Carcinogenic Cumulative Risk						0.0218	0			0.013	0
Non-carcinogenic Cumulative Risk						0.0028	0			0.002	0

Values shown in the sixth and tenth columns are the normalized fraction of the risk based level, and not the carcinogenic risk level. The fraction of risk multiplied by 10⁻⁵ equals the carcinogenic risk level for the carcinogenic compounds. Carcinogenic compounds shown in bold. >1E+308 indicates that the DAF value is greater can be calculated in excel (i.e. compounds are essentially immobile) and 1/>1E+308 indicates that the risk and or equilibrium concentration is very low (inconsequential).

Table 4		Potential Cumulative Risk Assuming All Pathways Complete										DRO, GRO and RRO not included in cumulative risk calculations	
Page 9		Tank 117 Example				Remote Site, Alaska							
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Compounds		Fraction of Target Soil Ingestion Risk, Residential Site	Fraction of Target Outdoor Air Inhalation Risk, Residential Site	Fraction of Target Indoor Air Inhalation Risk, Residential Site	Fraction of Target Groundwater Ingestion Risk, Residential Site	Sum of Fraction of Risk Values for Residential Site	Residential Site Check for compliance with risk levels (0= in compliance; 1= not in compliance)	Fraction of Target Soil Ingestion Risk, Industrial Site	Fraction of Target Outdoor Air Inhalation Risk, Industrial Site	Fraction of Target Indoor Air Inhalation Risk, Industrial Site	Fraction of Target Groundwater Ingestion Risk, Industrial Site	Sum of Fraction of Risk Values for Industrial Site	Industrial Site Check for compliance with risk levels (0= in compliance; 1= not in compliance)
Benzene (c & nc)	nc	6.16E-05	1.18E-05	0.0012	0.0171	0.0184	0	3.06E-06	3.98E-06	2.88E-04	0.0122	0.0125	0
Toluene (nc)	nc	8.01E-04	5.82E-06	5.29E-04	0.0342	0.0356	0	3.98E-05	1.97E-06	1.26E-04	0.0245	0.0246	0
Ethylbenzene (c & nc)	nc	6.81E-04	1.08E-05	8.11E-04	0.0279	0.0294	0	3.38E-05	3.67E-06	1.93E-04	0.0199	0.0202	0
Xylenes (total) (nc)	nc	0.0031	5.20E-04	0.0389	0.0892	0.1317	0	1.54E-04	1.76E-04	0.0093	0.0637	0.0733	0
GRO Aromatics (nc)	nc												
DRO Aromatics (nc)	nc												
RRO Aromatics (nc)	nc												
GRO Aliphatics (nc)	nc												
DRO Aliphatics (nc)	nc												
RRO Aliphatics (nc)	nc												
Acenaphthene (nc)	nc	8.22E-05	0.00E+00	0.00E+00	0.0091	0.0092	0	1.23E-05	0.00E+00	0	0.0065	0.0065	0
Acenaphthylene (nc)	nc	2.50E-05	0.00E+00	0.00E+00	0.0046	0.0046	0	3.73E-06	0.00E+00	0	0.0033	0.0033	0
Anthracene (nc)	nc	1.14E-06	0.00E+00	0.00E+00	3.65E-04	3.66E-04	0	1.25E-07	0.00E+00	0	2.61E-04	2.61E-04	0
Benzo(g,h,i)perylene (nc)	nc	1.72E-04	0.00E+00	0.00E+00	0.0037	0.0038	0	2.57E-05	0.00E+00	0	0.0026	0.0026	0
Fluoranthene (nc)	nc	4.07E-04	0.00E+00	0.00E+00	0.0068	0.0073	0	6.08E-05	0.00E+00	0	0.0049	0.005	0
Fluorene (nc)	nc	8.52E-05	0.00E+00	0.00E+00	0.0019	0.002	0	1.08E-05	0.00E+00	0	0.0014	0.0014	0
Naphthalene (c & nc)	nc	7.18E-04	8.95E-05	0.0012	0.0137	0.0157	0	7.69E-05	3.03E-05	2.83E-04	0.0098	0.0102	0
Phenanthrene (nc)	nc	6.32E-06	0.00E+00	0.00E+00	9.13E-04	9.20E-04	0	6.91E-07	0.00E+00	0	6.52E-04	6.53E-04	0
Pyrene (nc)	nc	9.29E-04	0.00E+00	0.00E+00	0.0048	0.0058	0	1.39E-04	0.00E+00	0	0.0035	0.0036	0
Benzene (c & nc)	c	1.66E-04	1.18E-04	0.0121	0.1614	0.1738	0	2.40E-05	3.33E-05	0.0029	0.0961	0.099	0
Ethylbenzene (c & nc)	c	0.00E+00	5.11E-04	0.0383	0.00E+00	0.0388	0	0.00E+00	1.44E-04	0.0091	0.00E+00	0.0093	0
Benzo(a)anthracene (c)	c	0.0389	2.41E-07	3.39E-08	0.0081	0.047	0	0.0158	6.79E-08	8.08E-09	0.0048	0.0207	0
Benzo(b)fluoranthene (c)	c	0.0694	5.88E-08	4.81E-10	0.0103	0.0797	0	0.0282	1.66E-08	1.15E-10	0.0061	0.0343	0
Benzo(k)fluoranthene (c)	c	0.0069	9.38E-09	5.98E-11	6.43E-04	0.0076	0	0.0028	2.64E-09	1.42E-11	3.83E-04	0.0032	0
Benzo(a)pyrene (c)	c	0.0972	1.35E-07	5.07E-10	0.0471	0.1443	0	0.0395	3.81E-08	1.21E-10	0.0281	0.0676	0
Chrysene (c)	c	9.62E-04	6.93E-09	6.63E-10	4.07E-05	0.001	0	3.91E-04	1.95E-09	1.58E-10	2.42E-05	4.15E-04	0
Dibenz(a,h)anthracene (c)	c	0.1228	1.07E-06	4.55E-10	0.0686	0.1914	0	0.0499	3.02E-07	1.08E-10	0.0408	0.0907	0
Indeno(1,2,3-cd)pyrene (c)	c	0.0327	5.24E-09	9.05E-12	0.0056	0.0383	0	0.0133	1.48E-09	2.15E-12	0.0033	0.0166	0
Naphthalene (c & nc)	c	0.00E+00	3.91E-04	0.0052	0.00E+00	0.0056	0	0.00E+00	1.10E-04	0.0012	0.00E+00	0.0013	0
1,2,4-Trimethylbenzene (nc)	nc	1.97E-04	5.88E-05	0.0033	5.48E-04	0.0041	0	9.78E-06	1.99E-05	7.96E-04	3.91E-04	0.0012	0
1-Methylnaphthalene (nc)	nc	0.0036	4.86E-06	5.80E-05	0.0697	0.0734	0	3.85E-04	1.64E-06	1.38E-05	0.0498	0.0502	0
2-Methylnaphthalene (nc)	nc	0.0036	5.20E-06	5.71E-05	0.0685	0.0721	0	3.85E-04	1.76E-06	1.36E-05	0.0489	0.0493	0
Chlordane (c & nc)	nc	0.0024	3.10E-08	3.35E-08	0.0548	0.0572	0	2.01E-04	1.05E-08	7.98E-09	0.0391	0.0393	0
	nc												
	nc												
	nc												
Chlordane (c & nc)	c	5.29E-05	9.30E-10	1.01E-09	0.0411	0.0411	0	1.26E-05	2.62E-10	2.40E-10	0.0245	0.0245	0
	c												
	c												
	c												
	c												
	c												
	c												
Carcinogenic Cumulative Risk						0.7686						0.3677	0
Non-carcinogenic Cumulative Risk						0.4716						0.3041	0

Values shown in the second through sixth and eighth through twelfth columns are the normalized fraction of the risk based level, and not the carcinogenic risk level. The fraction of risk multiplied by 10⁻⁵ equals the carcinogenic risk level for the carcinogenic compounds. Carcinogenic compounds shown in bold.

Table 4		Cumulative Risk for Pathways Complete at Present Time										DRO, GRO and RRO not included in cumulative risk calculations	
Page 10		Tank 117 Example				Remote Site, Alaska							
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Compounds	Fraction of Target Soil Ingestion Risk, Residential Site	Fraction of Target Outdoor Air Inhalation Risk, Residential Site	Fraction of Target Indoor Air Inhalation Risk, Residential Site	Fraction of Target Groundwater Ingestion Risk, Residential Site	Sum of Fraction of Risk Values for Residential Site	Residential Site Check for compliance with risk levels (0= in compliance; 1= not in compliance)	Fraction of Target Soil Ingestion Risk, Industrial Site	Fraction of Target Outdoor Air Inhalation Risk, Industrial Site	Fraction of Target Indoor Air Inhalation Risk, Industrial Site	Fraction of Target Groundwater Ingestion Risk, Industrial Site	Sum of Fraction of Risk Values for Industrial Site	Industrial Site Check for compliance with risk levels (0= in compliance; 1= not in compliance)	
Benzene (c & nc)	nc	6.16E-05	1.18E-05	0.00E+00	0.00E+00	7.34E-05	0	3.06E-06	3.98E-06	0.00E+00	0.00E+00	7.04E-06	0
Toluene (nc)	nc	8.01E-04	5.82E-06	0.00E+00	0.00E+00	8.07E-04	0	3.98E-05	1.97E-06	0.00E+00	0.00E+00	4.17E-05	0
Ethylbenzene (c & nc)	nc	6.81E-04	1.08E-05	0.00E+00	0.00E+00	6.91E-04	0	3.38E-05	3.67E-06	0.00E+00	0.00E+00	3.74E-05	0
Xylenes (total) (nc)	nc	0.0031	5.20E-04	0.00E+00	0.00E+00	0.0036	0	1.54E-04	1.76E-04	0.00E+00	0.00E+00	3.30E-04	0
GRO Aromatics (nc)	nc												
DRO Aromatics (nc)	nc												
RRO Aromatics (nc)	nc												
GRO Aliphatics (nc)	nc												
DRO Aliphatics (nc)	nc												
RRO Aliphatics (nc)	nc												
Acenaphthene (nc)	nc	8.22E-05	0.00E+00	0.00E+00	0.00E+00	8.22E-05	0	1.23E-05	0.00E+00	0.00E+00	0.00E+00	1.23E-05	0
Acenaphthylene (nc)	nc	2.50E-05	0.00E+00	0.00E+00	0.00E+00	2.50E-05	0	3.73E-06	0.00E+00	0.00E+00	0.00E+00	3.73E-06	0
Anthracene (nc)	nc	1.14E-06	0.00E+00	0.00E+00	0.00E+00	1.14E-06	0	1.25E-07	0.00E+00	0.00E+00	0.00E+00	1.25E-07	0
Benzo(g,h,i)perylene (nc)	nc	1.72E-04	0.00E+00	0.00E+00	0.00E+00	1.72E-04	0	2.57E-05	0.00E+00	0.00E+00	0.00E+00	2.57E-05	0
Fluoranthene (nc)	nc	4.07E-04	0.00E+00	0.00E+00	0.00E+00	4.07E-04	0	6.08E-05	0.00E+00	0.00E+00	0.00E+00	6.08E-05	0
Fluorene (nc)	nc	8.52E-05	0.00E+00	0.00E+00	0.00E+00	8.52E-05	0	1.08E-05	0.00E+00	0.00E+00	0.00E+00	1.08E-05	0
Naphthalene (c & nc)	nc	7.18E-04	8.95E-05	0.00E+00	0.00E+00	8.07E-04	0	7.69E-05	3.03E-05	0.00E+00	0.00E+00	1.07E-04	0
Phenanthrene (nc)	nc	6.32E-06	0.00E+00	0.00E+00	0.00E+00	6.32E-06	0	6.91E-07	0.00E+00	0.00E+00	0.00E+00	6.91E-07	0
Pyrene (nc)	nc	9.29E-04	0.00E+00	0.00E+00	0.00E+00	9.29E-04	0	1.39E-04	0.00E+00	0.00E+00	0.00E+00	1.39E-04	0
Benzene (c & nc)	c	1.68E-04	1.18E-04	0.00E+00	0.00E+00	2.84E-04	0	2.40E-05	3.33E-05	0.00E+00	0.00E+00	5.73E-05	0
Ethylbenzene (c & nc)	c	0.00E+00	5.11E-04	0.00E+00	0.00E+00	5.11E-04	0	0.00E+00	1.44E-04	0.00E+00	0.00E+00	1.44E-04	0
Benzo(a)anthracene (c)	c	0.0389	2.41E-07	0.00E+00	0.00E+00	0.0389	0	0.0158	6.79E-08	0.00E+00	0.00E+00	0.0158	0
Benzo(b)fluoranthene (c)	c	0.0694	5.88E-08	0.00E+00	0.00E+00	0.0694	0	0.0282	1.66E-08	0.00E+00	0.00E+00	0.0282	0
Benzo(k)fluoranthene (c)	c	0.0069	9.38E-09	0.00E+00	0.00E+00	0.0069	0	0.0028	2.64E-09	0.00E+00	0.00E+00	0.0028	0
Benzo(a)pyrene (c)	c	0.0972	1.35E-07	0.00E+00	0.00E+00	0.0972	0	0.0395	3.81E-08	0.00E+00	0.00E+00	0.0395	0
Chrysene (c)	c	9.62E-04	6.93E-09	0.00E+00	0.00E+00	9.62E-04	0	3.91E-04	1.95E-09	0.00E+00	0.00E+00	3.91E-04	0
Dibenz(a,h)anthracene (c)	c	0.1228	1.07E-06	0.00E+00	0.00E+00	0.1228	0	0.0499	3.02E-07	0.00E+00	0.00E+00	0.0499	0
Indeno(1,2,3-cd)pyrene (c)	c	0.0327	5.24E-09	0.00E+00	0.00E+00	0.0327	0	0.0133	1.48E-09	0.00E+00	0.00E+00	0.0133	0
Naphthalene (c & nc)	c	0.00E+00	3.91E-04	0.00E+00	0.00E+00	3.91E-04	0	0.00E+00	1.10E-04	0.00E+00	0.00E+00	1.10E-04	0
1,2,4-Trimethylbenzene (nc)	nc	1.97E-04	5.88E-05	0.00E+00	0.00E+00	2.56E-04	0	9.78E-06	1.99E-05	0.00E+00	0.00E+00	2.97E-05	0
1-Methylnaphthalene (nc)	nc	0.0036	4.86E-06	0.00E+00	0.00E+00	0.0036	0	3.85E-04	1.64E-06	0.00E+00	0.00E+00	3.86E-04	0
2-Methylnaphthalene (nc)	nc	0.0036	5.20E-06	0.00E+00	0.00E+00	0.0036	0	3.85E-04	1.76E-06	0.00E+00	0.00E+00	3.86E-04	0
Chlordane (c & nc)	nc	0.0024	3.10E-08	0.00E+00	0.00E+00	0.0024	0	2.01E-04	1.05E-08	0.00E+00	0.00E+00	2.01E-04	0
	nc												
	nc												
	nc												
Chlordane (c & nc)	c	5.29E-05	9.30E-10	0.00E+00	0.00E+00	5.29E-05	0	1.26E-05	2.62E-10	0.00E+00	0.00E+00	1.26E-05	0
	c												
	c												
	c												
	c												
	c												
	c												
	c												
Carcinogenic Cumulative Risk						0.3701						0.1503	0
Non-carcinogenic Cumulative Risk						0.0176						0.0018	0

Values shown in the second through sixth and eighth through twelfth columns are the normalized fraction of the risk based level, and not the carcinogenic risk level. The fraction of risk multiplied by 10⁻⁵ equals the carcinogenic risk level for the carcinogenic compounds. Carcinogenic compounds shown in bold.

Table 4		Site Status Summary					
Page 12		Tank 117 Example				Remote Site, Alaska	
1	2	3	4	5	6	7	8
		Cumulative Risks for Residential Site (rounded to 1 significant digit)	soil ingestion check for compliance with risk criteria (0= in compliance; 1 or >1 = not in compliance; number is the number of carcinogenic and non-carcinogenic direct contact criteria exceeded)	migration to outdoor air check for compliance with risk criteria (0= in compliance; 1= not in compliance)	migration to indoor air check for compliance with risk criteria (0= in compliance; 1= not in compliance)	groundwater ingestion check for compliance with risk criteria (0= in compliance; 1 or >1 = not in compliance; number is the number of carcinogenic and non-carcinogenic direct contact criteria exceeded)	migration to groundwater check for compliance (0= in compliance; 1 = not in compliance)
Potential Carcinogenic Cumulative Fraction of Risk		0.8	0				0
Potential Non-carcinogenic Cumulative Risk		0.5	0				0
Existing Carcinogenic Cumulative Fraction of Risk		0.3701					
Existing non-carcinogenic Cumulative Risk		0.0176					
GRO Aromatics			0	0	0	0	0
DRO Aromatics			0	0	0	0	0
RRO Aromatics			0	0	0	0	0
GRO Aliphatics			0	0	0	0	0
DRO Aliphatics			0	0	0	0	0
RRO Aliphatics			0	0	0	0	0
check for ultimate GRO, DRO, RRO compliance			0				
Site conditions meet the ADEC human health risk standard established in 18 AAC 75.325. Site conditions are protective of human health under an unrestricted (residential) landuse scenario.							0
Migration to groundwater criteria are attained in surface and subsurface soils as per 18 AAC 75.340. These calculations may be used to support a Cleanup Complete determination.							0
Site meets the risk standard and migration to groundwater criteria established in the contaminated site regulations and may be closed as per 18 AAC 75.380 (provided ecological criteria also met). Eligible for a 'cleanup complete' determination							
Site soils appear suitable for use as vadose zone fill							
Site soils should not be used as saturated zone fill							
Site soils should not be used as wetlands or surface water fill							
A DRO polar fraction may be present, the risk posed by the polar fraction is not known.							
DRO water quality criteria in Table C have been exceeded in groundwater even though human health risk is within the acceptable range, therefore the risk calculations should not be used alone for a "Cleanup Complete" determination.							
Due to DRO exceeding Table C an institutional control restricting drinking water use or additional cleanup in the affected area may be required.							

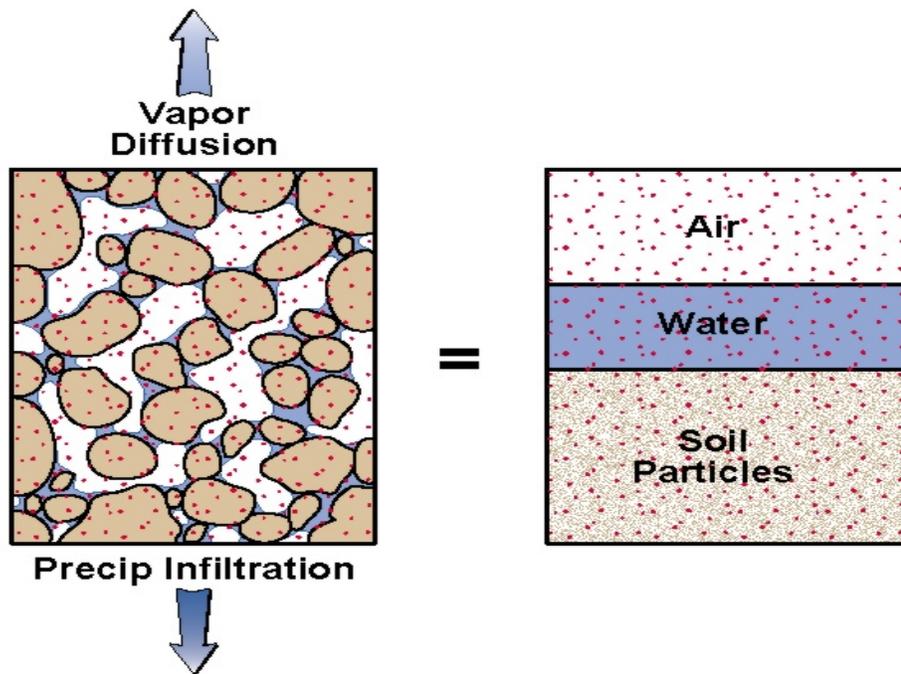


FIGURE 1
Block Diagram of a Soil Containing Dissolved, Vapor, and Adsorbed Hydrocarbon Phases

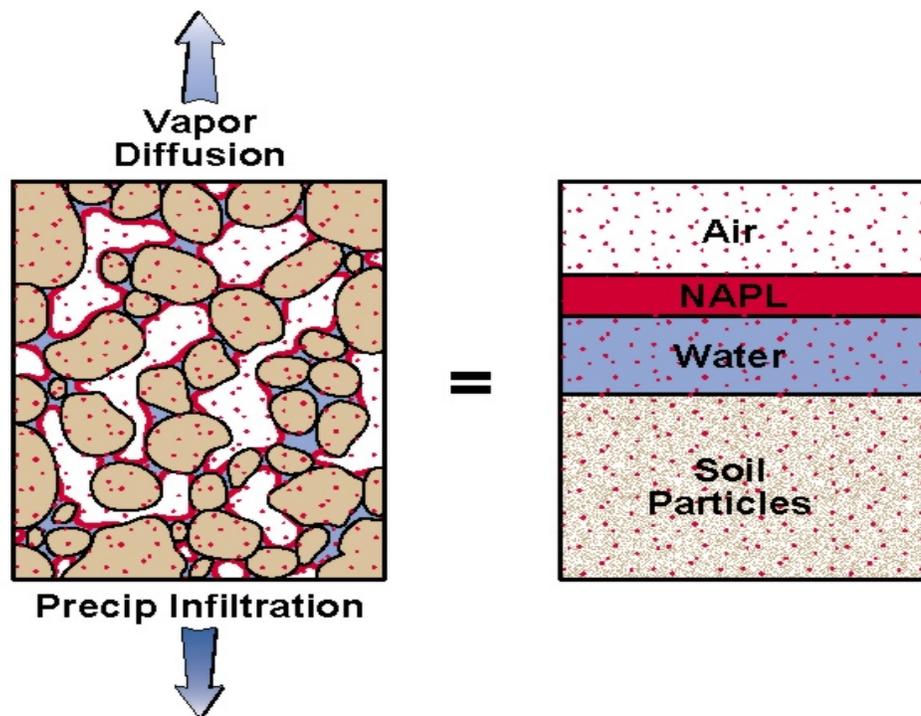


FIGURE 2
Block Diagram of a Soil Containing Dissolved, Vapor, and Adsorbed Hydrocarbons and NAPL

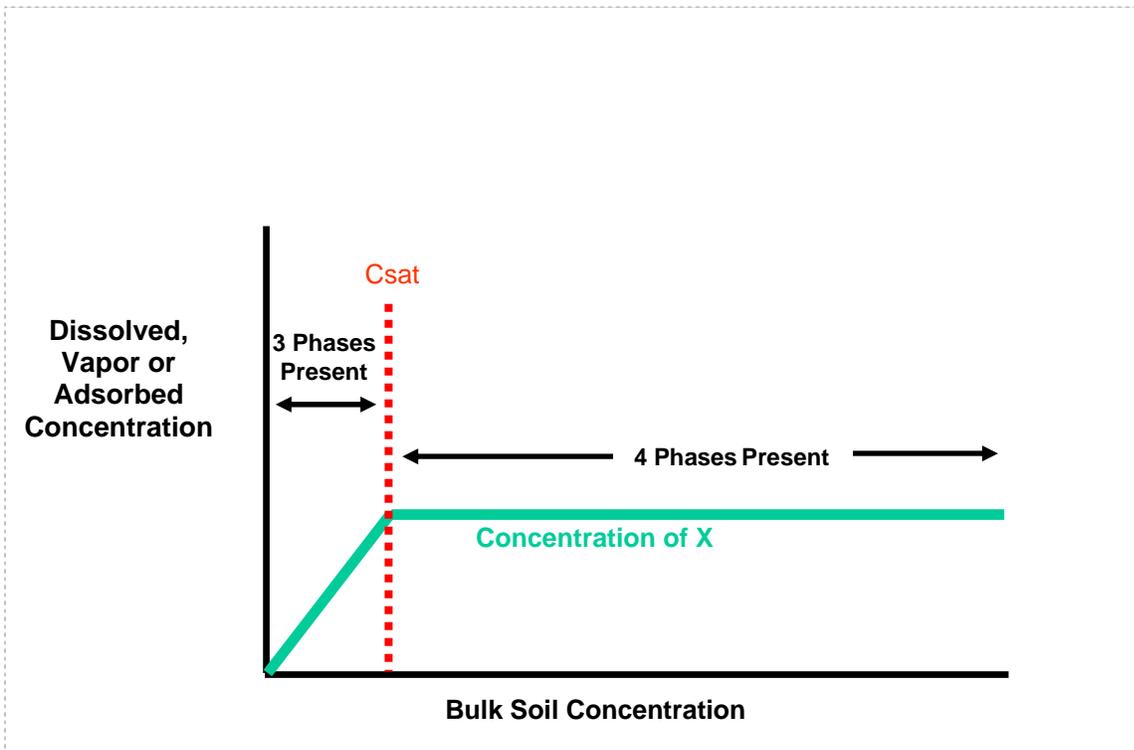


FIGURE 3
 Dissolved, Adsorbed and Vapor Phase Concentrations Increase Linearly with Increasing Bulk Soil Concentration Up to C_{sat} (the Soil Saturation Concentration) Where They Reach Their Maximum Values

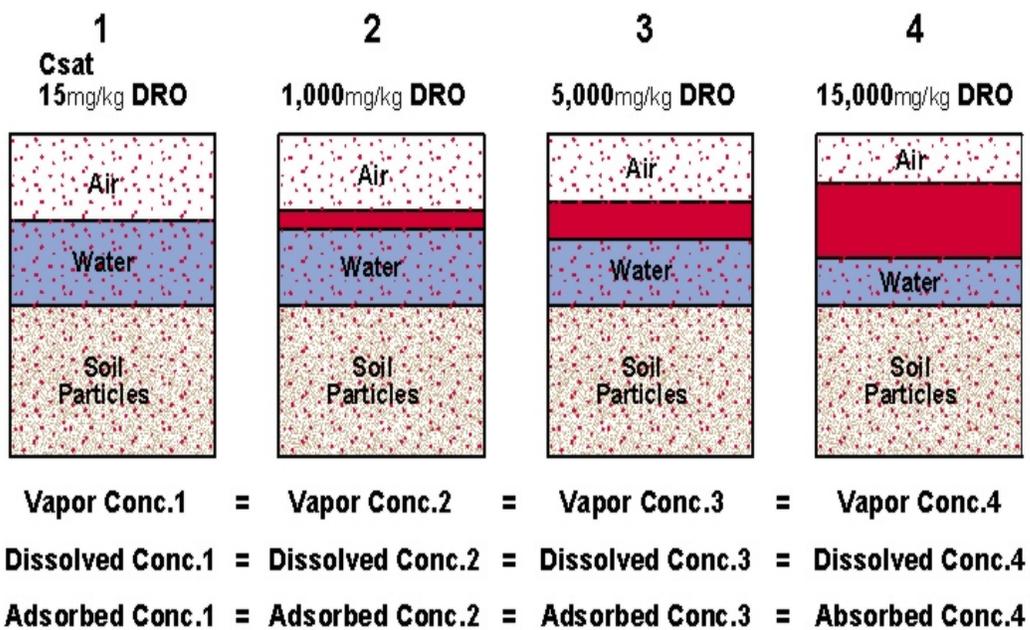


FIGURE 4
 Block Diagrams Showing That the Dissolved, Vapor, and Adsorbed Concentrations in Soil Do Not Increase as the NAPL Concentration Increases

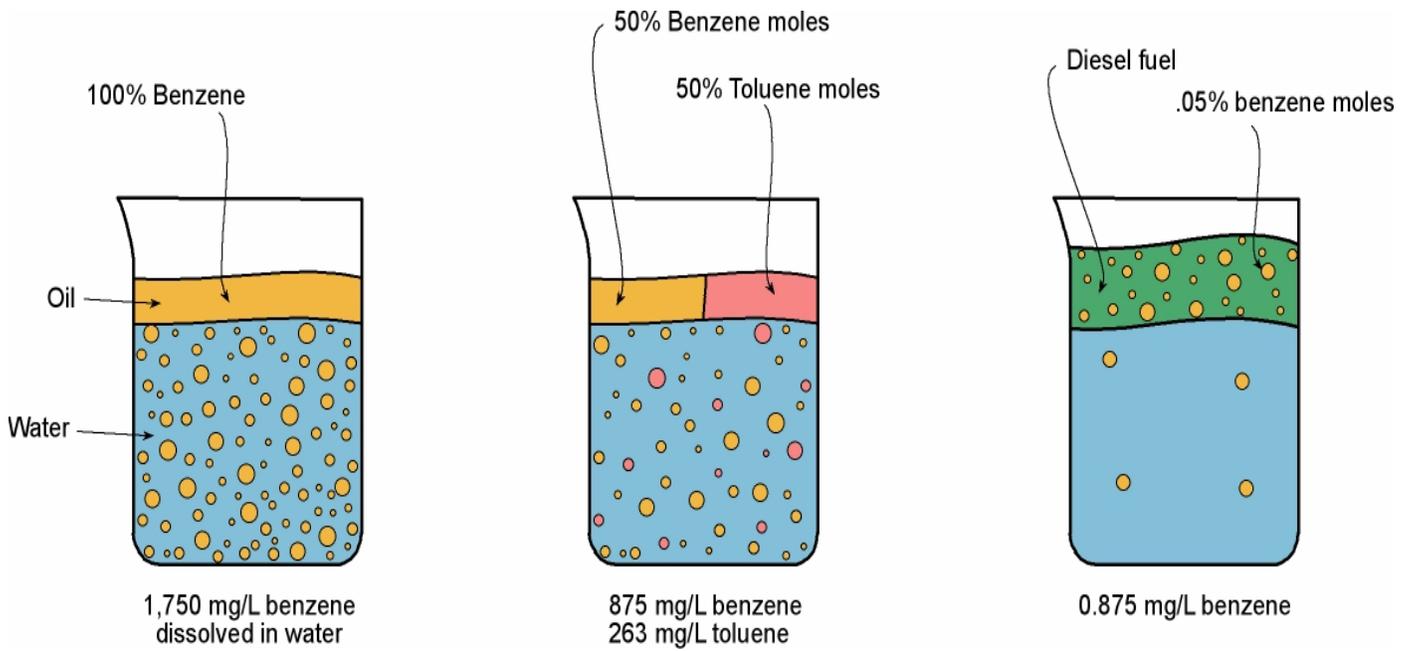


FIGURE 5
 Beakers of Water with Floating Hydrocarbon NAPL Layers Illustrating the Effect of Raoult's Law on the Solubility of Benzene

Rapid release surface spill spreads across ground surface before infiltrating.
In this example, the hydrocarbon is immobilized in the vadose zone.

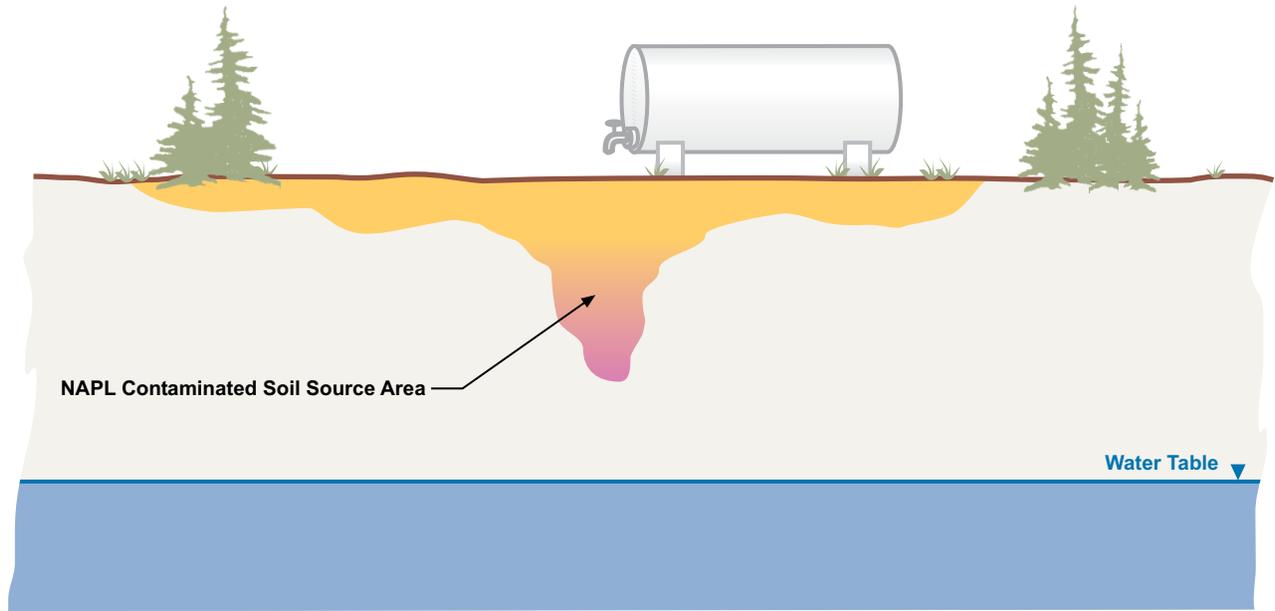


Figure 6. Vadose Zone NAPL Source Area from Surface Spill

Leak from a UST where the spilled hydrocarbon mass is not sufficient
to reach the water table.

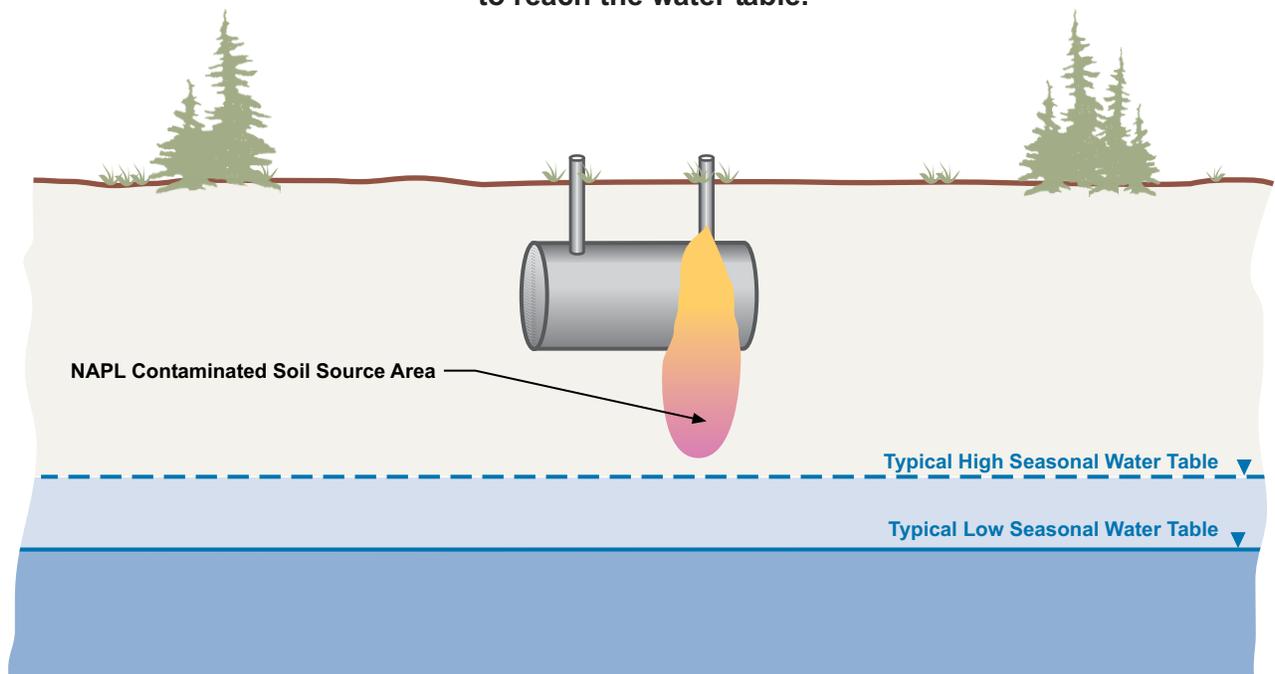


Figure 7. Vadose Zone NAPL Source Area from Subsurface Release

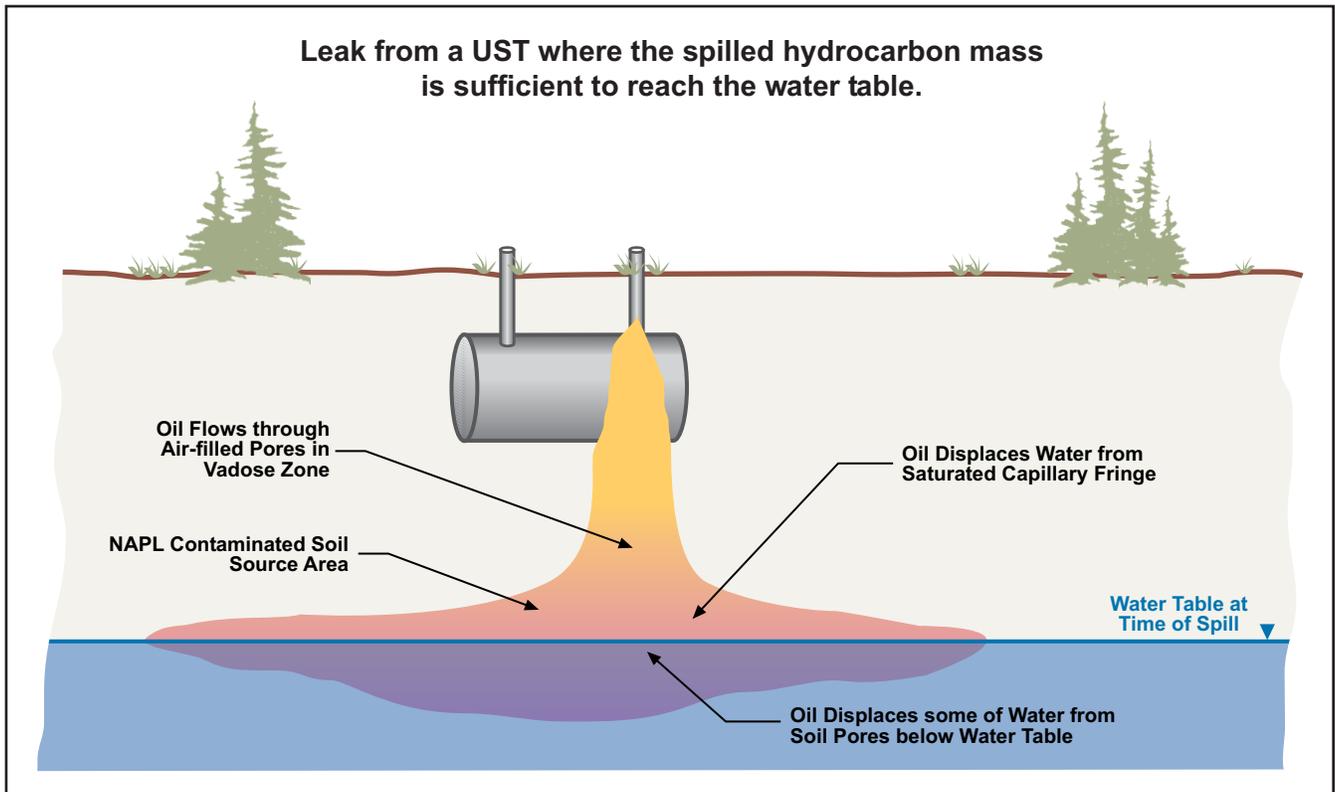


Figure 8. Saturated Zone NAPL Source Area from Subsurface Release

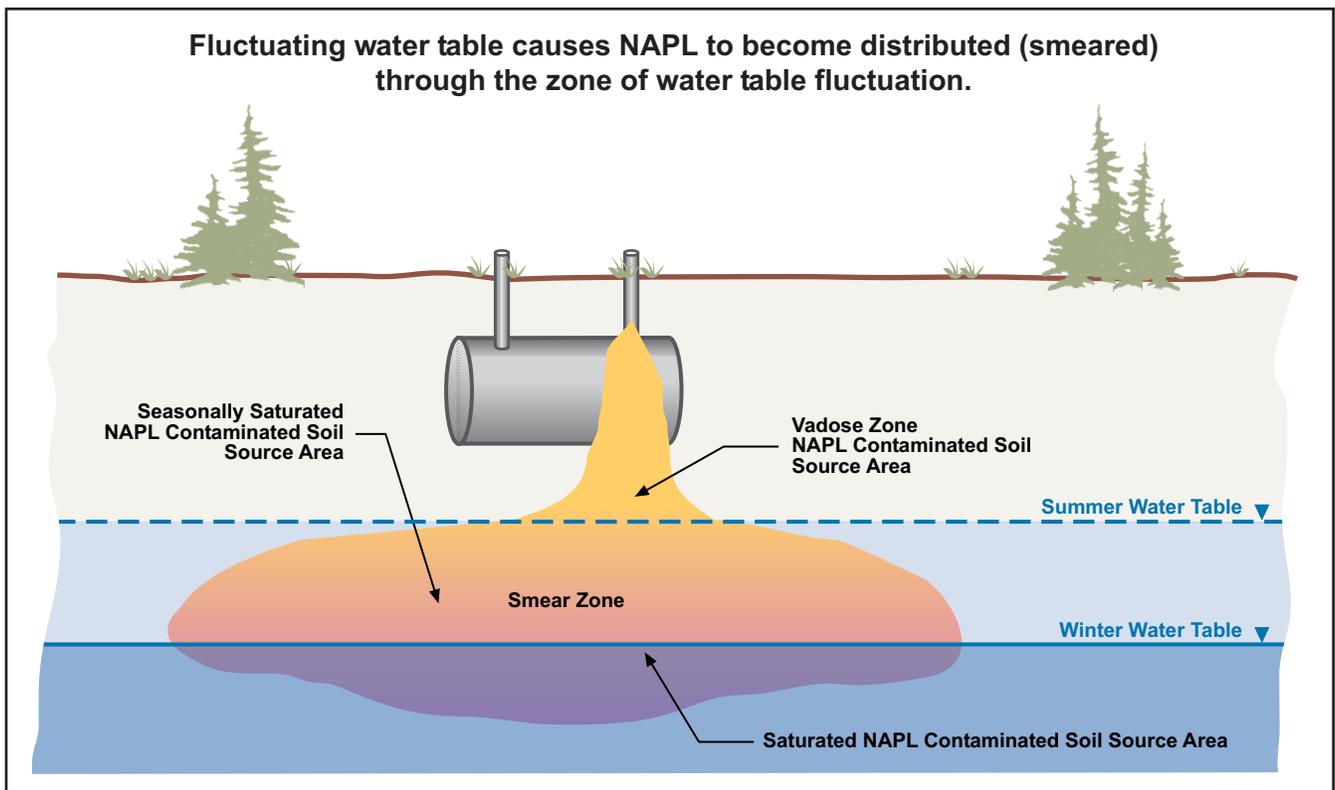


Figure 9. Saturated Zone NAPL Source Area Subject to Seasonal Groundwater Fluctuation

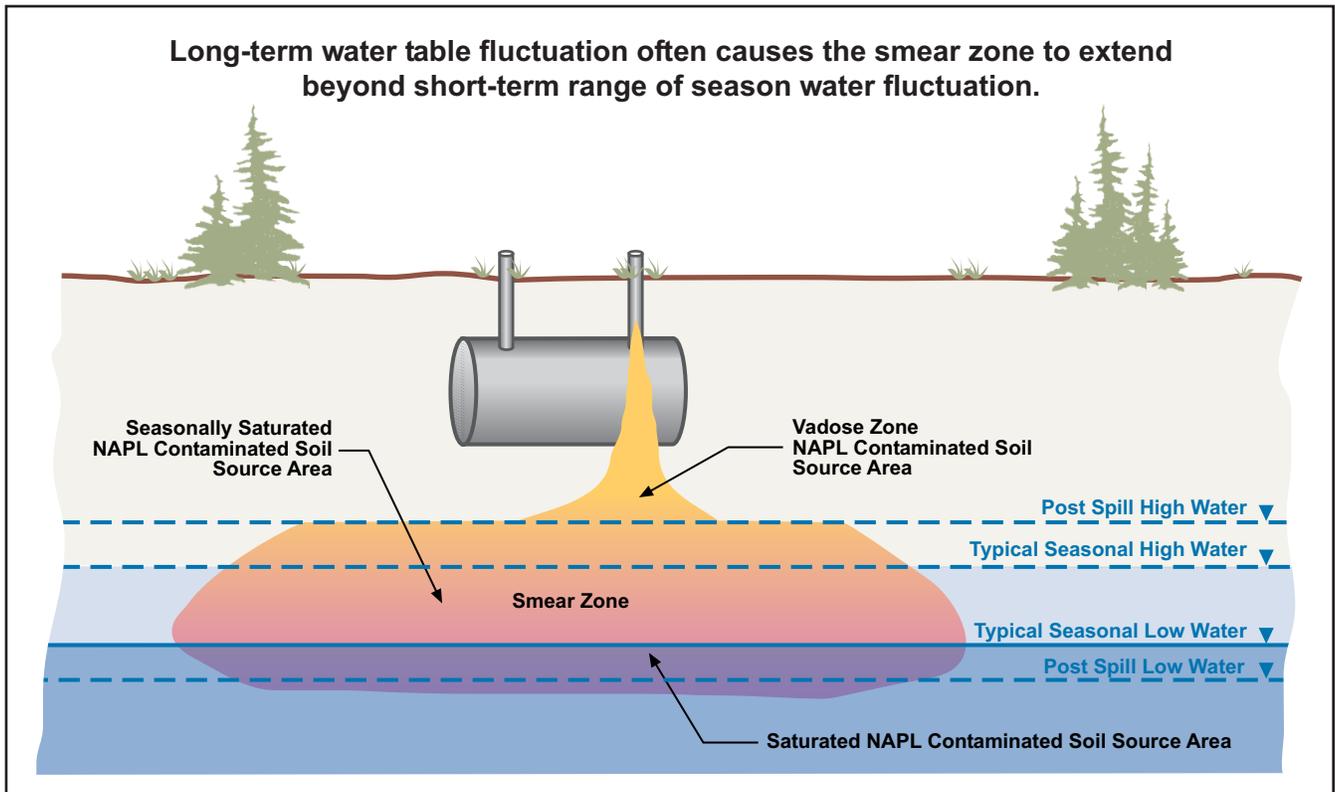


Figure 10 Saturated Zone NAPL Source Area Subject to Long-Term Groundwater Fluctuation

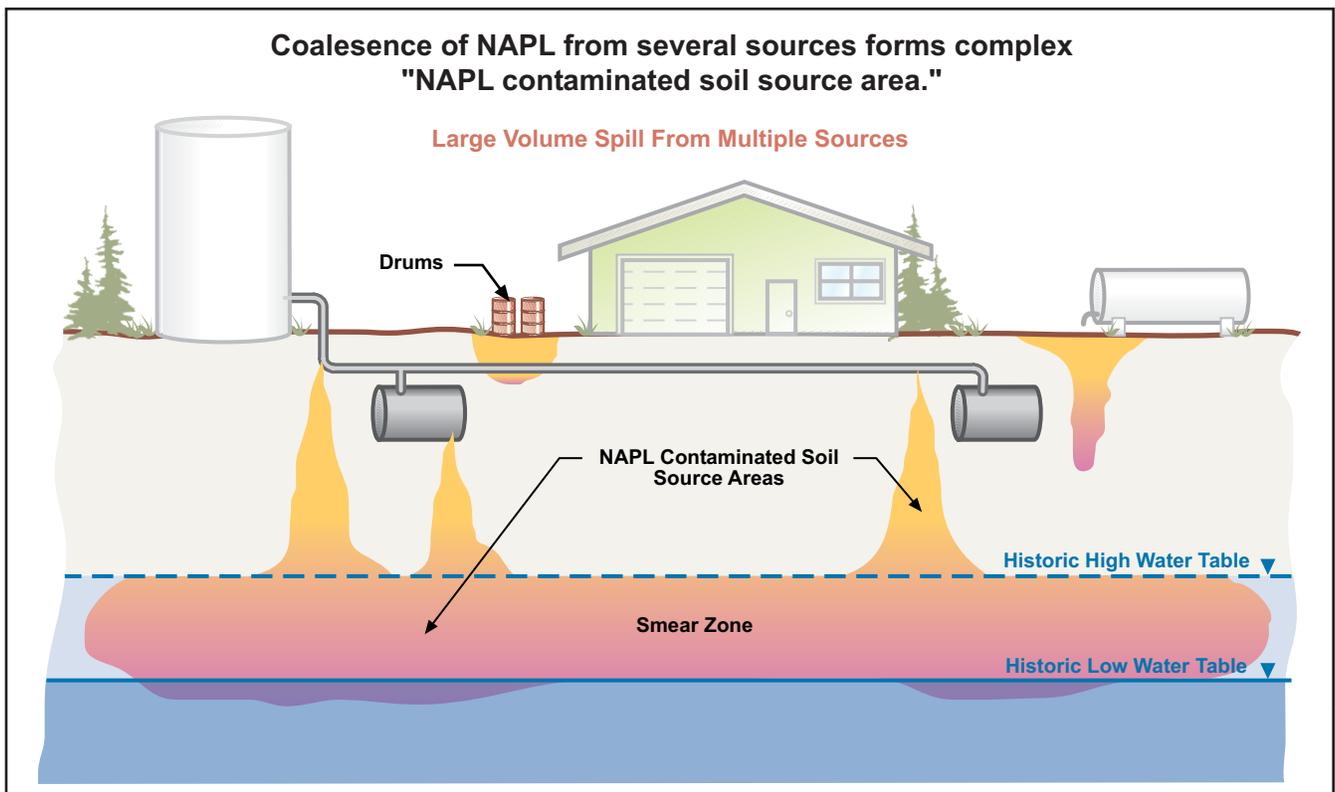
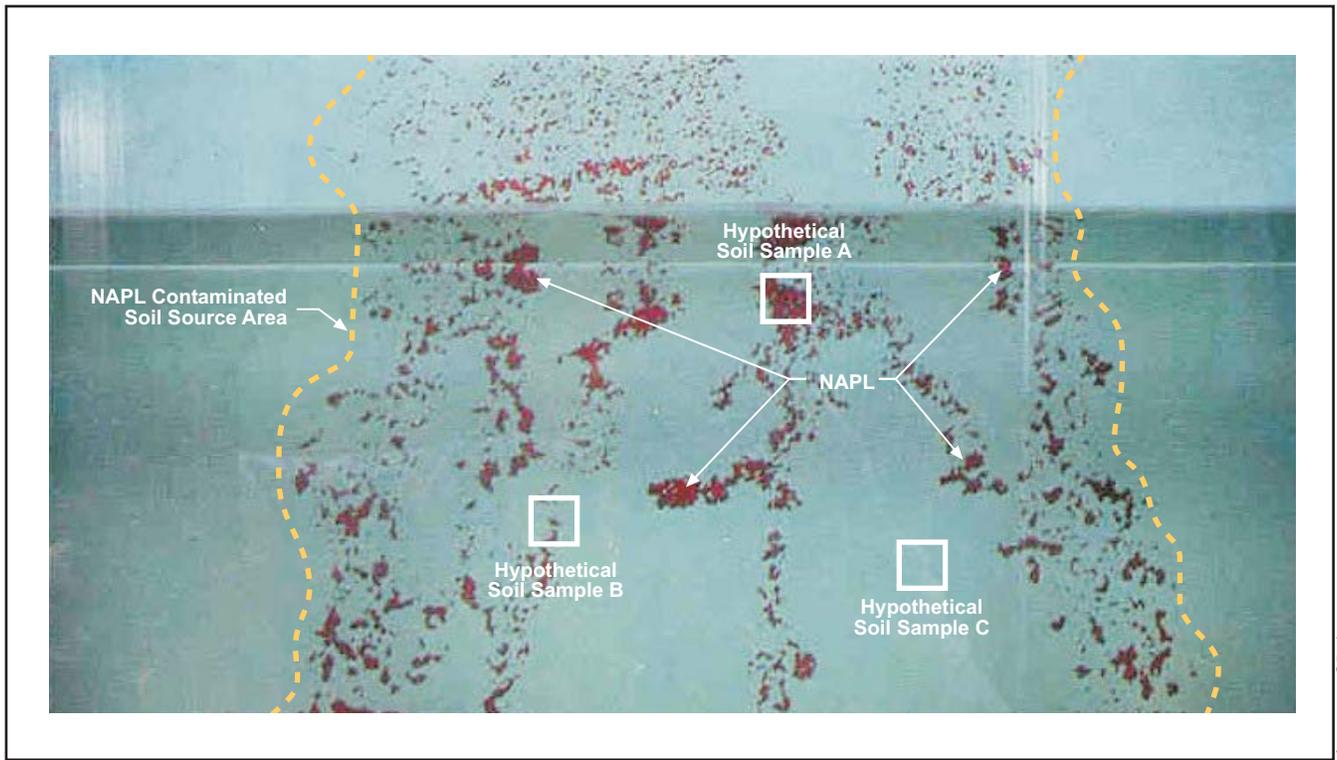


Figure 11 Complex NAPL Source Area Resulting From Multiple Releases

E012005001/ANC report figures 05/23/05 jp



EO12056/01/ANC report figures 05/23/05 JB

Figure 12 Sand Tank Example of NAPL Contaminated Soil Source Area

Appendix A
Site Characterization Recommendations

Site Characterization Recommendations

A1 Introduction

The calculation of risk posed by a contaminated site requires an accurate characterization of the site conditions because the site characterization is the foundation for the risk calculations. The purpose of this appendix is to recommend formats for the interpretation and presentation of site characterization data. Table A1 should be used during preparation of a site characterization report as a checklist to identify the type and sources of the data used in the calculations. Much of the required data for the site conditions report may best be presented in tables and maps, as described in subsequent sections. If multiple environmental reports exist for a site, then the site conditions report accompanying the risk calculations should incorporate and summarize the data from the previous reports as described in this appendix. The data collection and presentation required for the cumulative risk calculations are also the foundation for assessing remedial options and conducting the remedial design when remediation is necessary. Users of the hydrocarbon risk calculator must follow applicable ADEC regulations and guidance documents including, but not limited to, the following: Title 18, Chapter 75, of the *Alaska Administrative Code* (18 AAC 75); 18 AAC 78; Cleanup Levels Guidance (ADEC, 2008); Cumulative Risk Guidance (ADEC, 2008); Risk Assessment Procedures Manual (ADEC, 2010); Guidance For Data Reporting, Data Reduction, and Treatment of Non-Detect Values (ADEC, 2008); Draft Vapor Intrusion Guidance for Contaminated Sites (ADEC, 2009); Guidelines for Total Organic Carbon (TOC) Sample Collection and Data Reduction for Method Three and Method Four (ADEC, 2008); and Draft Field Sampling Guidance (ADEC, 2010).

In concept, a site conditions report would be submitted following the initial field investigations, (as described in Title 18, Section 75.335, of the *Alaska Administrative Code* [AAC]) and as necessary, following remediation (as described in 18 AAC 75.380). The site characterization report identifies whether site conditions pose an unacceptable risk, and the exposure routes and compounds that contribute most significantly to the cumulative risk.

- If following the initial site investigation, the site was found to present acceptable risks, then the existing concentrations would become the site “alternative cleanup levels” and the site would be eligible for a “cleanup complete” determination by the Alaska Department of Environmental Conservation (ADEC; as described in 18 AAC 75.380).
- If the site poses an unacceptable risk, then the exposure routes and compounds that contribute most significantly to the cumulative risk would be used to select a remedial and/or risk management approach for the site.
- If the site was originally found to pose a risk, the responsible party conducted a remedial action, and post-remediation monitoring demonstrates that the risk has been reduced to acceptable levels, then a new site conditions report documenting the site conditions following remediation would be prepared and submitted to the ADEC to meet the requirements of 18 AAC 75.380.

A primary objective of the site conditions report is to break the site down into zones where similar conditions exist and similar processes occur. The concentrations, concentration trends, and processes and risk can then be evaluated as necessary. In general, contaminated sites may be divided into zones or areas based on the following:

- Whether the hydrocarbon is present in three phases or four phases
- Whether the nonaqueous phase liquid (NAPL) is a) discontinuous or b) continuous and immobile at the site scale or c) continuous and mobile at the site scale
- The extent and concentration of the dissolved-phase plume
- Potentially the extent and concentration of the vapor-phase plume and
- The unaffected areas

In addition, the site conditions report should identify the site topography and setting, soil stratigraphy, geotechnical properties of the soil strata, hydrogeologic conditions, and relevant site infrastructure and property boundaries.

A2 NAPL-contaminated Soil Source Area

It is desirable to identify the “NAPL-contaminated soil source area,” which is defined as the contiguous, three-dimensional volume of soil that contains NAPL. Within the NAPL-contaminated soil source zone, four phases are present (or potentially present) and fuel hydrocarbons will partition into soil moisture, groundwater, soil gases, and soil organic carbon to establish a local equilibrium with the NAPL, as described by the four-phase equations with Raoult’s Law. The risk calculated using the hydrocarbon risk calculator is, in concept, the risk posed by the NAPL-contaminated soil source area. Fuel hydrocarbon concentrations in all phases should be higher within the NAPL-contaminated soil source area than in the surrounding three-phase areas. In addition, the NAPL-contaminated soil source is the likely remediation target if a remedial action is required, and assessment of intrinsic remediation requires an understanding of the extent of the NAPL-contaminated source area.

The NAPL- contaminated soil source area may be identified by compiling and reviewing the existing laboratory test results, soil log callouts of contaminated soils, field screening data (such as photoionization detector [PID] head space readings of soil samples), groundwater test results, and sampling notes. In addition, the location and depth (or elevation) of the data should be posted on maps or cross sections of the site. The laboratory results and field screening data may then be segregated based on whether they indicate the presence of NAPL. Indicators of the presence of NAPL include the following:

- Test results for soil with diesel-range organics (DRO) above about 10 to 50 milligrams per kilogram (mg/kg) and with gasoline-range organics (GRO) above about 200 mg/kg may generally be interpreted to indicate the presence of NAPL. Although DRO NAPL exists at concentrations above about 10 to 50 mg/kg, it is advised to use a working definition of the NAPL source area for DRO and GRO source areas as the area above the ADEC Table B2 migration to groundwater screening levels of 230 to 300 mg/kg, depending on the precipitation zone. For RRO source areas it is advised to use a working definition of NAPL contaminated soil source area as the area with RRO concentrations above about 250 mg/kg

(although C_{sat} calculations tell us that NAPL is present at much lower concentrations and Table B2 migration to groundwater screening levels are above 8,000 mg/kg).

- PID head space readings of thousands of parts per million (ppm) at recent gasoline spill sites, hundreds of ppm at recent diesel spill sites and old gasoline spill sites, and tens of ppm at old diesel spill sites likely indicate the presence of NAPL.
- Soil samples that have a hydrocarbon odor
- Soil samples that are reduced when surrounding samples display oxidized conditions
- Soil samples that show black or gray staining or an iridescent sheen when saturated
- Soil samples that fluoresce under ultraviolet light or fluoresce during a laser-induced fluorescence (LIF) survey
- Observations of free product on the water table in monitoring wells
- Water samples results above solubility limits—in particular, water samples with DRO concentrations above about 4 or 6 milligrams per liter (mg/L)
- Water samples that have a sheen

The sample locations that exceed or do not exceed these criteria will define the NAPL-contaminated source area (on both maps and cross sections, a boundary may be drawn separating the NAPL-contaminated soils from the soils that do not contain NAPL). Knowledge about the mechanics of migration of NAPL in the vadose zone and near the water table surface and the fluctuation of the water table will help identify the NAPL-contaminated soils. The distribution of hydrocarbon will likely be similar to one shown in Figures 6 through 11 of the user manual text. Note that soil concentrations within the NAPL-contaminated soil source zone may vary significantly in concentration and that there can be some uncontaminated samples within the NAPL-contaminated soil source zone. These conditions are illustrated in Figure 12 of the user manual text, which shows red-dyed hydrocarbon infiltrating through a tank filled with white sand. As shown in Figure 12 of the user manual text, Samples A through C are within the NAPL-contaminated soil source area, but Sample A has a much higher concentration than Sample B, and Sample C is uncontaminated. Because of this variability, it is generally not necessary to contour hydrocarbon concentrations within the NAPL-contaminated source area.

Color Coded Maps and Tables. Color coded symbols to identify the sample location and concentration ranges are recommended to allow a large amount of information to be conveyed quickly on maps and in tables. A very simple color coding system for NAPL source area maps that appears to work well involves the following highlighting: yellow for contaminated vadose zone sample locations, orange for contaminated smear zone and saturated zone sample locations, green for vadose zone samples that document the absence of NAPL, and blue for smear zone samples that document the absence of NAPL. (The referenced colors are only suggestions.) The NAPL source area would be the area containing the sample locations highlighted in yellow and orange and would exclude those highlighted in green or blue. Note that vadose zone samples that do not indicate the presence of NAPL tell relatively little about the site. Information about individual sample concentrations should be presented on the data tables and may be highlighted using the same colors as used on the maps. An alternative color coding system uses color to indicate the concentration range of the hydrocarbon and different

shape symbols to indicate the depth of the samples. Example maps are shown in Figures A1 and A2.

A detailed understanding of the shape of the vadose zone contamination may be gained by drilling numerous test holes, collecting and screening batches of soil samples, and laboratory-testing many soil samples. A detailed understanding of the NAPL-contaminated soil source area may help in the design of a remedial system because the NAPL-contaminated soil source area is the primary remedial target. However, a very detailed understanding of the shape of the NAPL-contaminated soil source area may not greatly improve human health risk calculations (given that enough data are available to characterize the source concentration). Therefore, the identification of the NAPL-contaminated soil source area may emphasize delineating the smear zone source area while acknowledging that the distribution of NAPL in the vadose zone is commonly within the smear zone footprint area but potentially complex.

A3 Free Product in Monitoring Wells

“Discontinuous” NAPL or oil is NAPL that is not continuously connected between adjacent soil pores, does not appear in site monitoring wells and is immobile under normal hydraulic gradients. Discontinuous NAPL is present as discontinuous blobs, ganglia, and pendular rings. “Continuous” NAPL or oil is NAPL that is continuously connected between adjacent soil pores over a significant area and appears in monitoring wells. The continuous oil may move between adjacent soil pores that contain continuous NAPL, but will only migrate downgradient into previously uncontaminated soils if it has an oil thickness or pressure greater than the water displacement pressure of the soil. Equations by Professor Charbeneau of the University of Texas, calculate the oil thickness that will allow the oil to migrate downgradient into previously uncontaminated soil pores; hence, this manual and SOC papers refer to this critical oil thickness as the “Charbeneau thickness.” (The Charbeneau thickness is described in a peer reviewed article in *Ground Water and Remediation* (Charbeneau, et. al. 2000) and in *American Petroleum Institute (API) Publication 4682* [Charbeneau et al., 1999]). Whether oil has the potential to migrate downgradient into previously uncontaminated soil pores is at the core of the free product cleanup criteria (18 AAC 75.325) and is an important concept for understanding site conditions, selecting remedial approaches and assessing engineering and institutional controls.

Any areas where free product is observed in monitoring wells are positively inside the NAPL-contaminated soil source area and a halo of discontinuous NAPL-contaminated soils surrounding the wells where free product was observed likely exists. The presence of free product in site monitoring wells indicates that continuous NAPL is present and it will be necessary to measure the free product thickness during a period of sustained low groundwater to assess the maximum or near-maximum thickness of oil that may accumulate at the site. The area where free product is observed in monitoring wells should be identified on site maps. One means of identification is drawing a polygon around the wells containing the NAPL (some monitoring wells from inside this area of continuous NAPL may not show oil on the water table). In addition, the thickness of NAPL observed should be measured and compared to the “Charbeneau thickness” for the soil texture present at the water table. The measured oil thickness data should be reported by posting the thicknesses on the site maps and/or by presenting the oil thicknesses in a table identifying the monitoring well number, date of the measurement, oil thickness, and piezometric surface elevation. If the measured NAPL thickness

is greater than about 50 percent of the Charbeneau thickness, then the mobility of the continuous oil may need to be assessed in greater detail (as described in the technical background document on maximum allowable concentrations and free product mobility [Geosphere and CH2M HILL, 2006a]). If the assessment of NAPL mobility indicates that oil is mobile at the NAPL source area scale, the portion of the site containing the mobile oil should be identified on the site maps.

A4 Examples of Maps and Tables Identifying the Source Area

Examples of maps, cross sections, and tables used to identify and display/document the NAPL-contaminated soil source area are shown in Figures A1 through A4 and Tables A2 through A4. The example sites are discussed below:

- The Davis Property site at Strawberry Point on Hinchinbrook Island is representative of a relatively small and simple site. The site was affected by diesel fuel leaking from an abovegrade pipeline joint. Figure A1 shows the borehole locations and, in gray highlights, the NAPL-contaminated soil source area. The table on the figure shows the PID, GRO, and DRO data from the site. (Table A2 provides BTEX, DRO, and GRO data). Comparison of the data in the table with the sample locations and depth shows that the samples collected inside the gray-highlighted area have DRO concentrations above 50 mg/kg and elevated PID head space values, and that outside the gray-highlighted areas, DRO concentrations are less than about 10 mg/kg and have generally lower PID readings. Note that the water table was at about the 6- to 7-foot depth during the site investigations and if NAPL was present in the zone of water table fluctuation, then samples from this depth should have detected the hydrocarbon. Note that even when samples are collected during a period of several years, the older data are still very useful in identifying the NAPL-contaminated soil source area (which is the initial objective). Because numerous borings and laboratory analyses are available to help identify the NAPL source area at the site, the map only highlights the NAPL source area, instead of showing a spider map or the DRO values. The diesel fuel at the Davis Property is interpreted to have been derived from one pipe joint and to have been released in sufficient quantity for the NAPL to have percolated to the water table, spread across the water table surface, and smeared throughout the zone of seasonal water table fluctuation. The smear zone portion of the NAPL source area forms a disc of contaminated soil about 20 to 30 feet in diameter.
- The second example site is the Federal Aviation Administration (FAA) Shop and Generator Building site at Strawberry Point on Hinchinbrook Island. The site has housed an air navigation aid for about 60 years. Site soils were affected by diesel fuel from fuel tank and pipe leaks and overfill/fuel-handling incidents. The site was remediated by air sparging and bioventing between 1996 and 2003. Figure A2 shows the borehole locations and, highlighted in gray, the NAPL-contaminated soil source area. Table A3 provides the laboratory data from the site. The top portion of Table A3 (Table A3A) contains the results from samples collected outside the NAPL source areas, and all analyses show DRO concentrations of less than about 10 mg/kg. The bottom portion of Table A3 (Table A3B) contains the results from samples collected inside the NAPL source area. The analyses show DRO concentrations above the DRO aliphatic soil saturation concentration and commonly greater than 1,000 mg/kg. Note that even though the samples were collected during a

period of several years and that some of the samples were collected during or following remediation, all the data are very useful in identifying the NAPL-contaminated soil source area (which is the initial objective). In a subsequent step, the most recent post-remediation data will be used to statistically characterize the current source concentrations. Because numerous borings and laboratory analyses are available to help identify the NAPL source area at the site, the map only highlights the NAPL source area instead of showing a spider map or the DRO values. The diesel fuel at Strawberry Point is interpreted to have been derived from numerous leaking tanks and pipes and to have been released in sufficient quantity for the NAPL to have percolated to the water table, spread across the water table surface, coalesced into a contiguous source, and smeared throughout the zone of seasonal water table fluctuation. The smear zone portion of the NAPL source area forms a disc of contaminated soil about 80 to 100 feet wide and 200 feet long. The long axis of the NAPL source area is almost perpendicular to the groundwater flow direction because the multiple spill and leak locations that created the source area are along a line that happens to be almost perpendicular to the groundwater flow direction. Soil boring descriptions of contaminated soil, PID screening, and the laboratory test results listed in Table A3 suggest that the majority of the NAPL source area and mass appears to be about 5 to 12 feet below grade in the zone of seasonal water table fluctuation. The laboratory test data also suggest that a relatively sharp or distinct boundary separates the NAPL-contaminated soil source area from the areas that were not affected by NAPL. This distinct boundary should be expected, given the capillary forces that control the migration of NAPL (as described in the technical background memo on maximum allowable concentrations and free product migration [Geosphere and CH2M HILL, 2006a]).

- The third example is from the Gold Creek spill site. Figure A3 is a map that identifies the NAPL-contaminated soil source area, the extent of free product in monitoring wells on a specific date, and the extent of the dissolved-phase plume. The NAPL-contaminated soil source area is labeled as the maximum extent of free product, and all of the wells within this area showed free product on the water table in the first few months after the spill. The map also shows the portion of the site where free product was observed in monitoring wells and the portion of the site where the free product thickness was greater than 0.5 foot during an October 2002 monitoring event. (The 0.5-foot thickness is an arbitrary thickness not related to mobility.) The thicknesses of free product measured in selected monitoring wells on October 4, 2002, are posted on the map. The extent of the dissolved-phase plume above 1.5 mg/L is shown as encompassing the NAPL source area and a relatively small downgradient area. Figure A4 is a cross section approximately along the groundwater flow path that shows the NAPL-contaminated soil source area consisting of the path of infiltrating hydrocarbon in the vadose zone and the disc of contaminated soil in the zone of seasonal water table fluctuation.

A5 Statistical Characterization of the NAPL-contaminated Soil Source Area Hydrocarbon Concentrations

The hydrocarbon concentrations used as input to the hydrocarbon risk calculator need to balance the desire to protect human health and the environment with the need to accurately represent site conditions. Consistent with the description in U.S. Environmental Protection Agency (EPA) risk-assessment guidance (EPA, 2002) and as explicitly stated in an ADEC

technical memorandum (ADEC, 2003), “the arithmetic average concentration measured in a representative group of samples collected from the exposure area is generally considered the most appropriate and representative value for use as the concentration term in environmental risk assessment.” The EPA and ADEC also point out that (1) the arithmetic average concentration of a relatively small group of samples is only an estimate of the true mean, and (2) to protect human health, the 95 percent upper confidence level (UCL) of the mean should be used to conservatively represent the mean concentration. Therefore, to assess human health risk, the soil concentrations used as input to human health risk calculations should typically be the 95 percent UCLs of a representative data set that has been collected from within the exposure area. In a representative data set, the sample locations should be randomly selected (or the results of a biased sampling plan should be appropriately stratified or grouped), and the sample population should be large enough to characterize the site. As an alternative, the highest DRO, GRO, BTEX, and polycyclic aromatic hydrocarbon (PAH) concentrations measured at a site may be used in place of the 95 percent UCL of the mean if the highest DRO, GRO, BTEX and PAH concentrations do not indicate unacceptable risk. However, if the highest measured values suggest unacceptable risk, then 95 percent UCL values should be calculated.

In general, as the number of samples in a sample set increases, the 95 percent UCL value will tend to approach the mean or average concentration of the sample set. Hence, if the 95 percent UCL values indicate that an unacceptable risk exists, but the average or mean concentration of the sample set presents an acceptable risk, then the responsible party may want to consider collecting additional samples to better characterize the site and potentially reduce the 95 percent UCL value. If re-sampling is conducted, the new samples would ideally be collected at random locations inside the NAPL-contaminated soil source area. The intent of the re-sampling event is to increase the size of the data set used to statistically characterize the NAPL source area concentrations. Note that based on the re-sampling results, the source area size and shape could be redefined. Also note that most existing contaminated site data sets likely are biased high, because it is common to field screen samples (visual, olfactory, and PID screening) and to analyze the most heavily contaminated samples. The use of a biased-high data set makes the risk calculations conservative.

Exposure Area. In this document, the exposure area is interpreted to be the NAPL-contaminated soil source area. Hence, all samples from within the NAPL-contaminated soil source area that are representative of the site conditions at the time that the risk is assessed should be used to calculate the source area input concentrations. In the Strawberry Point Shop and Generator Building example (see Figure A2 and Table A3), the soil samples collected before and during remediation and the samples from outside the NAPL-contaminated soil source area were culled from the full data set to derive a data set representative of the time that the risk calculations were performed (Table A4). Calculating the risk associated with the NAPL-contaminated soil source area is conservative (compared with calculating the risk associated with a larger exposure area, as might be done in a Method 4 risk assessment).

95 Percent UCL Calculation Methods. Several methods and tools are available for calculating the 95 percent UCL values for input to the risk calculations. The most readily accepted approach would be to use the EPA-developed statistics calculator named ProUCL. The ProUCL software is available free from the EPA web site (www.epa.gov). The EPA ProUCL calculator assesses the data distribution and automatically selects the most appropriate method of calculating the 95 percent UCL. (An initial estimate of the 95 percent UCL, assuming a normal distribution,

may be calculated using Excel spreadsheet functions, but the ProUCL software, or an accepted alternative, should still be used to calculate the UCL for the risk calculations).

Use of Non-detect Values in Statistical Summaries. Laboratory analyses of samples from within the exposure area may not detect or report concentrations for some hydrocarbon compounds used as input to the four-phase calculator. When this occurs the user is advised to follow the ProUCL recommendations and ADEC guidance (2008d) for addressing the non-detect results. In general the non-detect results may be addressed in the calculation of the 95 percent UCL in several ways, such as:

- If the analysis result is listed as non-detect and a value below the method reporting limit but above the method detection limit is provided, this value may be used as the sample concentration. These values are commonly described as qualified or “J” flagged data and are usually available from the laboratory (but may have to be requested).
- If the analysis result is below the method detection limit, then the ND sample result may be excluded from the 95 percent UCL calculations or a substitute value of the method detection limit or one half the method detection limit may be used in the 95 percent UCL calculation. Note that the use of substitute value of half the detection is no longer recommended as the default approach (ProUCL, 2007 and ADEC 2008d).
- If the data set contains a low frequency of detection (a high proportion of non-detect values) then ProUCL states that simple ad hoc methods or the use of the sample median or mode may be as the exposure point concentration (with the concurrence of the decision makers). ProUCL also points out that when the majority of the data are non-detects the median and mode will also be a non-detect and the uncertainty associated with such estimates will be high.

If a substitute value of the method detection limit is used in the calculation of the 95 percent UCL and the HRC indicates that risk criteria maybe exceeded, then the impact of using lower substitute values may be assessed (in a sensitivity analysis). Note that it is common, especially in older data sets, for compounds like benzene and PAHs to have not been detected, but to have relatively high detection limits, so that when a value of the detection limit is used as input to the calculation of a 95 percent UCL, the 95 percent UCL value causes a significant portion of the risk posed by the site.

Number of Samples Needed to Characterize the Source Area. No set number of samples is required to identify or characterize a NAPL source zone. Rather the number of samples needed to identify and characterize the source area will depend on many factors, such as the size of the source, heterogeneity of the soils, use of screening methods, knowledge of the primary source of the spilled hydrocarbon (tank or pipeline leak location), and knowledge of the site hydrogeology. ProUCL can calculate a 95 percent UCL with as few as four samples, but as described, the greater the number samples in the data set, the more that the 95 percent UCL approaches the mean (the lower the 95 percent UCL value). Some site investigations use “step-out” borings to locate the edge of a source area. At sites with small source areas and large step-outs, this approach may result in only one or two source area samples and four or more uncontaminated samples. This limited number of source area samples will tend to complicate the characterization of source area concentrations and calculation of risk. Enough DRO/residual-range organic (RRO), GRO, and BTEX samples from each NAPL-contaminated

source need to be collected to statistically characterize the 95 percent UCL. Consider the following when determining the number of samples: greater numbers are better than lesser numbers of laboratory analysis results; the greater the number of samples in the data set, the more that the 95 percent UCL approaches the mean (the lower the 95 percent UCL value); some samples that investigators thought were contaminated inevitably turn out to be uncontaminated, there is inevitably some sample breakage and some laboratory data will not meet quality control standards so the investigation typically ends up with fewer source zone samples than expected; ADEC will tend to take a conservative perspective; and the cost of the laboratory analysis is relatively small compared to the costs of contracting, writing work plans, mobilizing to the site, writing inconclusive reports, and then having to return to the site to conduct additional investigations and/or implement institutional controls and conduct remediation. For all these reasons, the best practice is to be sure to collect the data needed to characterize the source while on site! Run more source zone analyses than you think you need!

Samples for PAH and aromatic and aliphatic equivalent carbon characterization should be from the more heavily contaminated portions of the source area. (PAH and aromatic and aliphatic equivalent carbon analyses generally should not be run on soil samples from outside the NAPL source area.) Several (three or more) samples from each significant source area should be analyzed by the volatile petroleum hydrocarbon (VPH) and/or extractable petroleum hydrocarbon (EPH) test methods to assess the aromatic and aliphatic distribution of the bulk hydrocarbon.

Example Data Tables. Tables A2 through A4 show example data sets used in the calculation of 95 percent UCL values for the Strawberry Point sites – the Davis Property and the Shop and Generator Building site – displayed in Figures A1 and A2. Table A2 presents data from the Davis Property site and contains three parts as follows: Table A2A lists all of the 2003 laboratory test results; Table A2B lists the samples from the source area used in the 95 percent UCL calculation and the mean, standard deviation, standard deviation of the mean, and 95 percent UCL, value assuming a normal distribution for the data set; and Table A2C lists the groundwater laboratory test results. Table 3A shows DRO concentrations before remediation. Table A4 presents data from the Shop and Generator Building site following remediation and contains three parts as follows: Table A4A lists all of the 2003 laboratory test results; Table A4B lists samples from the source area that were collected after remediation and were used in the 95 percent UCL calculation. Note that DRO data from 2000 were included in the statistical evaluation even though some minor remediation occurred after 2000. The inclusion of the 2000 data yields a larger data set, which allows a better characterization of the source area (the 95 percent UCL is closer to the mean), given that relatively little remediation occurred after 2000.

A6 Dissolved-phase Plume Characterization

The dissolved-phase plume is the three-dimensional volume of groundwater containing dissolved-phase hydrocarbons. At most fuel hydrocarbon spill sites, the dissolved phase is caused by partitioning of the hydrocarbon from the NAPL into the dissolved or aqueous phase. This dissolution process tends to establish a local equilibrium, and as dissolved hydrocarbon is transported (advected) downgradient of the source area by the flowing groundwater and/or biodegrades in the source area, more hydrocarbon dissolves into the groundwater from the NAPL. Because of biodegradation and hydrodynamic dispersion, the dissolved concentration

will decrease downgradient of the NAPL source area. At most spill sites, the majority of the hydrocarbon mass will be in the NAPL phase, not in the dissolved phase (or adsorbed or vapor phases).

Dissolved-phase Plume Mapping. The dissolved-phase plume area may be subdivided into areas based on whether a three- or four-phase distribution is present, and based on the hydrocarbon concentrations in the plume. This subdivision process may result in distinct mapped areas as described below.

If the NAPL source area extends into the saturated zone (that is, the NAPL extends below the water table) as it does at most Alaskan spill sites, then in the saturated portion of the NAPL-contaminated soil source area, a four-phase distribution will exist and the dissolved-phase equilibrium concentration (that is, the concentration in the groundwater) should follow Raoult's Law. The dissolved plume, which coincides with the NAPL-contaminated smear zone in the soil source area, may be described as the source area plume and will be delineated by the identification of the NAPL source area in the smear zone.

A three-phase distribution will exist downgradient of the saturated portion of the NAPL-contaminated soil source area because of advection of the contaminants; in the saturated zone below the source because of advection and hydrodynamic dispersion; and lateral to the source because of hydrodynamic dispersion. If the NAPL source is entirely above the water table, there may be a dissolved-phase plume in the saturated zone below the NAPL source caused by infiltrating precipitation. The dissolved-phase plume downgradient of the source area may be described as the "downgradient dissolved-phase plume." If a portion of the downgradient dissolved-phase plume exceeds the risk-based criteria for groundwater concentration in 18 AAC 75 Table C, then that portion of the plume should be delineated on the maps. In addition, tables of the groundwater laboratory test results should be provided in the site conditions report. The dissolved-phase plume area exceeding the risk based Table C criteria may require an institutional control and/or remediation to protect to human health while the plume persists.

In addition, the portion of the downgradient dissolved-phase plume exceeding the Alaska Ambient Water Quality Criteria should be identified on the site maps to assess whether the dissolved-phase plume above ambient water quality criteria extends to a surface water body. If the dissolved plume above ambient water quality criteria extends to a surface water body, then the impact of the plume on the water quality in the surface water body may need to be determined. If the dissolved plume does not extend to a surface water body or is below the ambient water quality criteria at the edge of the water body, then the plume may be considered to not adversely affect the surface water body and to be in compliance with environmental criteria.

Characterization of the Dissolved-phase Plume Hydrocarbon Concentration Trend. As described above, in the conceptual model of a fuel hydrocarbon release the dissolved-phase plume will tend to expand farther downgradient and increase in concentration for a period of time (possibly a few years) following the hydrocarbon release and then stabilize in area and concentration for an extended time (years to decades) as the NAPL source is depleted. To make good site management decisions and accurately assess risk, the responsible party and ADEC need to know whether the dissolved-phase plume is expanding, stable, or contracting. At fuel hydrocarbon spill sites that are decades old, the dissolved-phase plume may be assumed to be

stable or shrinking. At recent spill sites, the stability of the dissolved-phase plume may be assessed by conducting a Mann-Kendall trend analysis of concentrations in the plume. The Mann-Kendall trend analysis describes the likelihood that the plume is expanding, stable, or contracting. EPA documents and several textbooks describe the Mann-Kendall trend analysis (Bedient et. al., 1999). In addition or as an alternative, groundwater fate and transport modeling using a simple screening tool such as BioScreen (Newell et. al., 1997) or Modflow and MT3D may be used to assess the time required for the dissolved-phase plume from a new spill to reach its maximum extent. The fate and transport modeling data may be very useful in developing long-term monitoring programs for recent spill sites.

Characterization of the Dissolved-phase Plume Hydrocarbon Concentrations. Consistent with ADEC policy, the maximum measured dissolved-phase concentration in a relatively recent, representative data set is the input value for calculations of groundwater-ingestion risk. Note that the DRO concentrations measured in groundwater in the NAPL-contaminated soil source area may commonly be above the solubility limit for diesel fuels, indicating that the groundwater samples contained NAPL or that polar biodegradation byproducts are present. (To identify whether NAPL or polar compounds are present, the measured aromatic and aliphatic concentrations should be compared to the aromatic and aliphatic solubility limits and calculated equilibrium concentrations; and the aromatic and aliphatic concentration should be compared to the total DRO concentration.) The value of data from water samples containing NAPL is limited for many reasons, including the following:

- The NAPL does not migrate with the groundwater; hence, the data cannot be used to assess the source term in transport models.
- The sampling method and technique, groundwater elevation, and well development effort often affects the NAPL concentration in the water sample; hence the concentration data may be invalid for groundwater concentration trend analysis.
- The high concentrations caused by NAPL incorporation in groundwater samples may result in overestimates of human health risk.

The overestimate of human health risk occurs because maximum concentrations from shallow, poorly developed monitoring wells are commonly used to characterize the groundwater that could be consumed by persons at the contaminated sites, whereas drinking water wells at hydrocarbon spill sites generally do not tap the shallow water sampled by monitoring wells and drinking water wells are typically developed extensively compared to monitoring wells. (Drinking water well development tends to reduce or eliminate sediment production and NAPL entrainment.) In addition, long-term consumption of water containing NAPL is not likely because the water would smell like fuel, taste like fuel, and have a sheen that would alert the user to the presence of the contamination. In contrast, dissolved-phase contamination above risk-based levels may not exhibit a smell or taste and would not have a sheen to alert the consumer to the presence of the contaminant; hence, long-term consumption of the tainted water could persist undetected. For the above reasons, sampling techniques that limit NAPL and sediment inclusion in groundwater samples are advised. These methods include low-flow sampling and possibly the use of diffusion bag samplers.

A7 Hydrogeologic Data

The hydraulic conductivity and groundwater gradient are valuable site data that should be documented at most sites (especially where the hydrocarbon has reached the water table). Several methods are available to measure or estimate the hydraulic conductivity, such as conducting pump tests or slug tests, permeameter testing of soil samples, and estimating the conductivity based on sieve analyses. Slug tests and small-scale pump tests using 2-inch monitoring wells and data loggers can be accomplished in about 2 to 4 hours and offer valuable data relative to the time invested. The slug test and/or small-scale pump test data can be readily reduced and documented using any of several commercially available pump test software programs, spreadsheets, or hand calculations. The software typically graphs the drawdown data for the pump test, calculates the conductivity, and prints a simple report that can be included in the site conditions report as an appendix.

At the lowest level of effort, the groundwater gradient and flow direction may be determined by measuring the depth to groundwater in a minimum of three monitoring wells, by using swing ties and a level survey to establish the location and collar elevations on the monitoring wells, then using a graphical technique (Fedder, 1986) to calculate the flow direction and gradient. If the site is large (10,000+ square feet), then more than three wells will likely be necessary to document the gradient and characterize the extent of the dissolved-phase plume. In general, as many wells as possible should be used to document the gradient and flow direction. (For example, if a site has five or eight monitoring wells, all of them – not just three monitoring wells – should be gauged and used to assess the flow direction and gradient). When more than three wells are used to assess the gradient, a surface contouring program such as Surfer® (Golden Software) may be used to document the groundwater contours and gradient. When contouring programs such as Surfer® are used, the well locations from which the contoured data were derived should always be highlighted, and blanking files should be used to limit the display of contours outside the area of data. (The contouring algorithms commonly cause the contours to misleadingly splay apart outside the area of the monitoring wells.) When calculating the gradient it is desirable to show the location or locations that were used in the calculation. Provided the soils are isotropic, the groundwater flow direction will be perpendicular to the groundwater contours. The groundwater Darcy velocity may be calculated as the hydraulic conductivity multiplied by the gradient.

The aquifer's saturated thickness is used in calculations of the dilution-attenuation factor and is valuable data when assessing potential impacts to drinking water supplies. The thickness of the aquifer may be documented by drilling deep test holes near the release site, or by using data from other boring/geologic studies of the area. The U.S. Geological Survey (USGS) and Alaska Department of Geological and Geophysical Surveys (DGGs) have published hydrogeologic data, and the Alaska Department of Transportation and Public Facilities (ADOT&PF) and municipalities often have libraries of test hole and well logs related to road and utility construction projects.

An example of a groundwater contour map is shown in Figure A5. This map from the Gold Creek project shows the NAPL-contaminated soil source area, the groundwater contours at 0.5-foot intervals, the wells from which water elevation data were derived (identified by black dots at the well locations), and the groundwater flow direction and gradient at two locations are

shown. Note that the map was made using blanking files, an approach that limits the splay of contours outside the data collection area, and more than 50 data points.

The water table should be expected to rise and fall seasonally, and this change in water table elevation should be documented at sites with groundwater contamination above levels in 18 AAC 75 Table C. Among the types of information affected by the seasonal variation are calculation of the dilution-attenuation factor, characterization of the smear zone thickness, modeling of the dissolved-phase plume extent, and assessment of the plume stability (the Mann-Kendall concentration trend analysis may have to be adjusted for seasonal concentration changes related to water table elevation and precipitation changes). The characterization of the water table fluctuation may be as simple as presenting water table elevation data from the existing monitoring events in a report table (listing the monitoring well number, observation data, and water table elevation) or using the hydrocarbon concentration data and sample depth information to identify the approximate smear zone. Note that the groundwater elevation data that are collected should be representative of both periods of low water (typically late winter conditions) and high water (typically late spring/breakup or autumn). The groundwater flow direction and gradient also may change as the groundwater elevation changes. If the site is large and/or complex, then data logger records are an excellent way to document the water table fluctuation.

A8 Soil Input Parameters for the Hydrocarbon Risk Calculator

The soil properties of contaminated sites greatly influence the fate and transport, risk, and remedial options associated with the site; therefore, the site characterization effort needs to document several key soil parameters. The soil properties used in calculations with the hydrocarbon risk calculator are listed Table 1 of the User Manual and highlighted in yellow in the hydrocarbon risk calculator spreadsheet. These values should ideally be based on the site-specific measurements or should match the ADEC default soil properties (but the ADEC default values should not be used if they are obviously not appropriate). Soil characterization needs and methods are briefly discussed in the following sections. When an American Society for Testing and Materials (ASTM) standard method exists to measure a soil parameter, that method should be used. In general, the soils data should be presented by using tables, cross sections, and maps, and should be related to the site stratigraphy.

Soil Stratigraphy and Soil Texture/Grain Size Distribution. Soil stratigraphy (as described here) involves describing the layers of soils present at the site and, as much as possible, attributing those layers to a depositional process or environment. Examples of soil stratigraphy that may be encountered at Alaskan sites include the following:

- Silty, over-bank fluvial deposits, overlying coarse-grained stream channel sediments
- Aeolian loess overlying glacial till
- Glaciofluvial outwash
- Colluvium overlying fractured bedrock
- Interbedded fine and coarse sands deposited in a fluvial environment overlying marine clays

Knowledge of the soil stratigraphy forms a framework for understanding the site and surrounding area soils (for example, the lateral continuity of aquifers and vapor migration pathways).

Soil textures or the grain size distribution should be documented because the soil textures greatly influence the capillary properties, soil moisture content, and hydraulic conductivity. The soil textures of each major stratigraphic layer at the site should be described and, to the extent practical, soil from each layer should be sampled and analyzed by sieve and/or hydrometer. If sieve and hydrometer measurements are not made, then the fraction of the soil mass in the gravel, sand, silt, and clay-sized particle ranges should be estimated. The soils should be assigned to a Unified Soil Classification System (USCS) group. If the soils are described in more detail than simply identifying their USCS group, then the ASTM descriptions listed in standard D-432 should be used (arbitrary or consultant-specific classification/description systems are not as helpful). Note that if layered soils are discovered at the site, then the soil stratigraphy and texture descriptions should identify the presence of the layering, thickness of the layers, and sharpness of the contacts between the layers. Interlayered soils, such as an interlayered sand and silt soil, should not be mixed, analyzed for grain size distribution, and then described as sandy silt. Rather, the interlayered soils should be described as being interlayered; for example, 0.5- to 2-inch-thick, fine to medium, sand lenses interlayered with 6- inch-thick silt and/or clay layers.

Soil Bulk Density, Porosity, and Moisture Content. The soil bulk density, soil moisture content, total porosity, air-filled porosity, and water-filled porosity values are used in the phase-partitioning calculations and the migration-to-indoor- and migration-to-outdoor-air risk calculations. Soil bulk density is a measure of the weight of the soil particles per unit volume of the porous media (grams per cubic centimeter [g/cm^3] or pounds per cubic feet [lb/ft^3]). The soil bulk density is usually measured by driving a cylindrical sampler (for example, a brass liner) into the soil and extracting a relatively undisturbed, known volume of soil and measuring the wet and dry weights of the known volume of soil. The gravimetric moisture content of the soil is calculated from the wet and dry soil weights, and the total porosity is calculated based on either a measured or estimated specific gravity of the soil solids. The water-filled porosity may be readily calculated from the soil moisture data, and the air-filled porosity may be calculated from the total porosity and water-filled porosity data.

Fraction of Organic Carbon. The fraction of organic carbon (f_{oc}) is used in the phase-partitioning calculations performed by the four-phase cumulative risk calculator, and in modeling dissolved-phase migration (in which the presence of organic carbon in the aquifer causes the dissolved-phase plume to be retarded relative to the groundwater velocity). The ADEC default f_{oc} value of 0.001-gram of organic carbon per gram of soil is commonly described as the point above which adsorption into the organic carbon dominates the adsorption process. (At f_{oc} values below about 0.001, adsorption into clay minerals may be as significant as adsorption into the naturally occurring organic carbon.) The ADEC default f_{oc} value may be used in calculations or the soil f_{oc} values may be measured in (four or more) soil samples collected from the impacted soil strata and near or below the water table depth, outside the NAPL-contaminated soil source area (as described in the ADEC guidance, 2008e). Note that the dissolved- and vapor-phase equilibrium concentrations calculated by the hydrocarbon risk calculator are less sensitive to the f_{oc} value than those values calculated by the three-phase model.

A9 Recommended Survey Accuracy

Site conditions and geographic location information contained in a site conditions report, such as soil borings, monitoring wells, test pits, property corners, easements, infrastructure (buildings, roads, parking lots, utilities), and geologic or terrain features (changes in slope, stream and lake shorelines, vegetation breaks) will have significant value long after the report has been submitted and a determination of the site status has been made. Accurate survey information is necessary to be able to identify the locations of environmental site data after infrastructure and site conditions have changed (for example, after buildings have been removed and/or vegetation has grown over a site). Therefore, high-quality survey data are recommended for all contaminated site reports. The overall objective of these survey recommendations is to help document the site conditions and to support the environmental decisions being made about the site. On a site-specific basis, a less-detailed and/or less-accurate survey may be acceptable, provided the existing data supports the decision being made. Note that the following survey approaches are recommendations, not requirements.

Surveying should generally be performed in accordance with the Alaska State Professional Land Surveyors (ASPLS) Standards of Practice as appropriate for the services being provided. Surveying should be generally conducted by, or under the direct supervision of, a Professional Land Surveyor (PLS) holding a current registration in the State of Alaska.

Site conditions and geographic location information contained in the site conditions report, such as soil borings, monitoring wells, property corners, infrastructure, and geologic or terrain features relevant to the project should be fully documented and geo-referenced to the Alaska State Plane Coordinate System of 1983 (North American Datum [NAD] 83, in U.S. Survey feet). Metadata (details on the survey methods and accuracy) should be provided for all geographic information.

The primary project survey control should originate from the National Geodetic Survey (NGS) Continuously Operating Reference Stations (CORS) referenced to NAD83 (CORS Epoch) system. The NGS Online Positioning Users Service (OPUS) utility should be used to establish the primary control coordinates for at least two project control points. The control survey conducted with a global positioning system (GPS) should consist of at least two independent 4-hour GPS static observations at each of the two control points (yielding a total of 8 hours of observation at each point and a total of 16 hours of observation at the two control points). The GPS observations at the two control points must be simultaneous observations. Subsequent GPS and conventional surveys for locating soil borings, monitoring wells, property corners, geologic features, and infrastructure should be tied directly to the primary project control. If existing survey data are translated to State Plane coordinates, then the translation parameters must be provided. Elevations should be referenced to the North American Vertical Datum of 1988 (NAVD88) established at each control point by using OPUS. The elevations of monitoring wells should be tied directly to the primary control by using differential leveling techniques and should be reported the nearest 0.01 feet.

Boundary surveys should be performed to Third Order, Class I standards, as specified by the ASPLS Standards of Practice, with an allowable error of closure of 1 to 10,000 or better.

Before starting the survey, the surveyor should review title reports, title documents, and mapping that are relevant to the project. The surveyor also should research additional relevant

documentation from other sources. These documents may include, but are not limited to, the following:

- Bureau of Land Management (BLM) and Department of Natural Resources (DNR) land status plats
- BLM township survey plats
- Mineral and U.S. Survey plats and field notes
- Any records of survey, subdivisions, and relevant engineering control surveys
- U.S. Coast and Geodetic Survey (USC&GS)/NGS control diagrams-descriptions
- ADOT&PF right-of-way records and other easement or boundary documents of record
- ADOT&PF engineering as-builts
- DNR surveys
- Aerial photographs

One legible portable document format (PDF) copy of the research materials should be in the files of the RP and submitted to ADEC on a compact disc (CD) for all of the above-referenced reports, plats, notes, and other source materials.

All research for property corner ties (generally includes local platting authority subdivision plats and right-of-way plats, BLM U.S. Surveys, state land survey plats, waiver documents, deeds, record of surveys, and monument records) should be completed before searching and tying property controlling corners is started.

Preliminary engineering information should be analyzed to determine where additional property boundary ties are needed, and title reports relevant to the project site should be examined. When preparing base maps, the surveyor should thoroughly review and document existing right-of-way rights and analyze preliminary engineering information to determine where additional survey ties are needed. Survey conflicts with existing right-of-way and boundary locations should be identified. If boundary survey conflicts are resolved, then a written summary of the rationale for the solution should be provided.

A survey base map should be prepared for the entire project limits and should include the following information:

- Project Control
- Soil borings, monitoring wells, geologic features, and infrastructure
- Existing property boundaries, including all Public Land Survey System survey lines
- All subdivisions, including name, plat number, and lot and block designations or aliquot parts description
- Existing rights-of-ways and easements
- Horizontal and vertical control statement

- Projection/Coordinates Table, scale, units, source

In addition to the survey described above, the site conditions report should include the results of a title search conducted by a professional title search company. The title search results should be submitted as an appendix to the site conditions report.

In general, hand-held GPS data and swing ties from building corners, by themselves, are not sufficient for the site conditions report for the following representative reasons:

- Buildings and similar structures are not permanent features, and after the buildings are removed, it may be impossible to recreate the contaminant locations.
- Hand-held GPS data have errors of tens of feet and are subject to operator error (for example, the hand-held GPS user does not know the datum for the measurement, the accuracy of the measurement, and/or how to report the measurement).

An example of the recommended data is presented in Figure A2, from the Strawberry Point project. Figure A2 shows a section line passing through the NAPL-contaminated soil source area, a 33-foot easement on either side of the section line, and differing land status among the sections (that is, Section 15 is part of the Chugach National Forest and selected by both the State of Alaska and Eyak and Chugach Native corporations, and Section 16 is subject to an interim conveyance to Eyak and Chugach Native corporations).

A10 References

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TABLE A1
Data to be Included in the Site Conditions Summary Report

Data Description	Notes	Default Value	Source of Data	Hydrocarbon Risk Calculator Input
Land Status				
Land Use Scenario & Zoning Classification	Residential or Industrial		ADEC Default	Yes
Land Ownership Boundaries & Title search results for subject site				No
Documentation of the presence or absence of Off Site Migration				
Land Ownership Boundaries & and title search results for adjacent properties if off-site migration is occurring				
Potential Groundwater Use	Potable or Non-potable Water		ADEC Default	Yes
Current Groundwater Use Scenario	not currently used or current use			
Professional Survey Coordinates for wells, property corners, source area limits, etc.				
Source and Age of spill	leaking UST, surface spill event			
Soils Characterization				
Stratigraphy Description				
Grain Size Analyses				
USCS Classification & ASTM soil descriptions				
Soil Bulk Density		94 lbs/ft ³	ADEC Default	Yes
Specific Gravity		2.65	ADEC Default	Yes
Soil Moisture Content		20%	ADEC Default	Yes
Total Porosity		0.44	ADEC Default	Yes
Water Filled Porosity		0.21	ADEC Default	Yes
Air Filled Porosity				Yes
Soil Organic Carbon Content		0.001	ADEC Default	Yes
Hydrogeology (by stratigraphic unit)				
Hydraulic Conductivity		0.002 cm/sec	ADEC Default	Yes
Hydraulic Gradient		0.0018	ADEC Default	Yes
Aquifer Saturated Thickness		100	ADEC Default	Yes
Precipitation Rate		20 inches/year	ADEC Default	Yes
Seasonal Water Table Fluctuation				Yes
Heterogeneity & Anisotropy				
Calculation of Dilution Attenuation Factor				Yes
Source Characterization				
3D NAPL Contaminated Volume Identified				
Source Length	perpendicular to groundwater flow	105 ft.		Yes
Source Width	parallel to groundwater flow			
Source Saturated Thickness	measured at high water level	0 ft.		Yes
NAPL characterization (EPH data from source area or use fresh fuel assumption)				Yes
Dissolved Phase Plume above Table C Values Identified				
Dissolved Phase Plume above AWQC Identified--documentation that surface water is or is not impacted				
Mann-Kendal Trend Analysis for Dissolved phase plume				
Source Area Groundwater and Soil Concentrations 95% UCL	95% UCL Soil Concentration (mg/kg)		Maximum Water Concentration (mg/L)	
Benzene				Yes
Toluene				Yes
Ethylbenzene				Yes
Xylene				Yes
GRO				Yes
DRO				Yes
DRO aromatics				Yes
DRO aliphatics				Yes
RRO				Yes
Naphthalene				Yes
Acenaphthene				Yes
Fluorene				Yes
Anthracene				Yes
Fluoranthene				Yes
Pyrene				Yes
Benzo (a) Anthracene				Yes
Chrysene				Yes
Benzo (b) fluoranthene				Yes
Benzo (k) fluoranthene				Yes
Benzo (a) pyrene				Yes
Indeno (1,2,3-cd) pyrene				Yes
Dibenz (a,h) anthracene				Yes
Free Product Data				
Identify if free product is present in monitoring wells				
Document free product thickness during periods of stable & low groundwater				
Compare to Charbeneau thickness for given soil type				
Document detailed assessment of free product mobility as necessary				
Document Soil Moisture Retention Properties as Necessary				
Intrinsic Remediation Parameters				
Dissolved Oxygen Data				
Nitrate Data				
Ferrous Iron Data				
Manganese Data				
Sulfate Data				
Methane Data				
Determination of primary electron acceptor & rate function				
Remediation History				
Excavation, Bioventing, Air Sparging history as appropriate				
Risk Characterization				
4-phase calculator output				Yes
Institutional Controls in Place				
Document all Institutional Controls that are in Place				
Long Term Monitoring Plan in Place				
Document all Monitoring Plans that are in Place				
Site Status				
Complete the Site Status Map form and request the appropriate Status				

TABLE A2A
2003 BTEX, GRO & DRO Data, Davis Property, FAA Strawberry Point Station

Test Hole Number	Depth (ft. bgs)	Location	Date Collected:	Benzene			Toluene			Ethylbenzene			Xylenes			Gasoline Range Organics			Diesel Range Organics			Residual Range Organics		
				Lab Result mg/kg	Detection Limit mg/kg	Stat Value mg/kg	Lab Result mg/kg	Detection Limit mg/kg	Stat Value mg/kg	Lab Result mg/kg	Detection Limit mg/kg	Stat Value mg/kg	Lab Result mg/kg	Detection Limit mg/kg	Stat Value mg/kg	Lab Result mg/kg	Detection Limit mg/kg	Stat Value mg/kg	Lab Result mg/kg	Detection Limit mg/kg	Stat Value mg/kg	Lab Result mg/kg	Detection Limit mg/kg	Stat Value mg/kg
TH 161	7	Davis Property	11/03/2003	0.0160		0.0160	0.0610		0.0610	0.0160		0.0160	0.100		0.1000	ND	0.59	0.2950	ND	2	1	ND	2	1
TH 155	6.5	Davis Property	10/31/2003	ND	0.0039	0.0020	0.0190		0.0190	ND	0.0045	0.0023	0.039		0.0390	6.40		6.4000	1,100		1,100	5		5
TH 154	6	Davis Property	10/31/2003	ND	0.0022	0.0011	0.0100		0.0100	ND	0.0032	0.0016	0.018		0.0180	ND	0.24	0.1200	13		13			
TH 153	6	Davis Property	10/31/2003	ND	0.0024	0.0012	ND	0.0094	0.0047	ND	0.0024	0.0012	ND	0.013	0.0065	ND	0.91	0.4550	28		28			
TH 152	6	Davis Property	10/31/2003	ND	0.0028	0.0014	0.0120		0.0120	ND	0.0027	0.0014	ND	0.013	0.0065	ND	0.37	0.1850	ND	4	2	ND	4	2
TH 151	6.5	Davis Property	10/31/2003	0.0740		0.0740	0.2500		0.2500	ND	0.0350	0.0175	0.290		0.2900	52.00		52.0000	5,000		5,000	16.8		16.8
MW 115	7	Davis Property	11/03/2003	ND	0.0019	0.0010	ND	0.0071	0.0036	ND	0.0019	0.0010	ND	0.013	0.0065	ND	0.17	0.0850	ND	2	1	ND	2	1
MW 114	6	Davis Property	10/31/2003	ND	0.0057	0.0029	0.0310		0.0310	ND	0.0064	0.0032	0.038		0.0380	ND	0.99	0.4950	690		690	8.0		8
MW 114	4.5	Davis Property	10/31/2003	ND	0.0028	0.0014	0.0130		0.0130	ND	0.0031	0.0016	ND		0.0170	ND	0.40	0.2000	250		250	14.1		14.1
MW 109	6	Davis Property	10/31/2003	0.0140		0.0140	0.0660		0.0660	ND	0.0094	0.0047	0.079		0.0790	12.00		12.0000	1,900		1,900	37.7		37.7
MW 109	4.5	Davis Property	10/31/2003	ND	0.0029	0.0015	0.0160		0.0160	ND	0.0046	0.0023	0.059		0.0590	12.00		12.0000	2,100		2,100	76.5		76.5

TABLE A2B
Soil Source Area Characterization, Davis Property Site, Strawberry Point

Test Hole Number	Depth (ft. bgs)	Location	Date Collected:	Benzene			Toluene			Ethylbenzene			Xylenes			Gasoline Range Organics			Diesel Range Organics			Residual Range Organics		
				Lab Result mg/kg	Detection Limit mg/kg	Stat Value mg/kg	Lab Result mg/kg	Detection Limit mg/kg	Stat Value mg/kg	Lab Result mg/kg	Detection Limit mg/kg	Stat Value mg/kg	Lab Result mg/kg	Detection Limit mg/kg	Stat Value mg/kg	Lab Result mg/kg	Detection Limit mg/kg	Stat Value mg/kg	Lab Result mg/kg	Detection Limit mg/kg	Stat Value mg/kg	Lab Result mg/kg	Detection Limit mg/kg	Stat Value mg/kg
TH 155	6.5	Davis Property	10/31/2003	ND	0.0039	0.0020	0.0190		0.0190	ND	0.0045	0.0023	0.039		0.0390	6.40		6.4000	1,100		1,100	5		5
TH 151	6.5	Davis Property	10/31/2003	0.0740		0.0740	0.2500		0.2500	ND	0.0350	0.0175	0.290		0.2900	52.00		52.0000	5,000		5,000	16.8		16.8
MW 114	6	Davis Property	10/31/2003	ND	0.0057	0.0029	0.0310		0.0310	ND	0.0064	0.0032	0.038		0.0380	ND	0.99	0.4950	690		690	8.0		8
MW 114	4.5	Davis Property	10/31/2003	ND	0.0028	0.0014	0.0130		0.0130	ND	0.0031	0.0016	ND	0.017	0.0085	ND	0.40	0.2000	250		250	14.1		14.1
MW 109	6	Davis Property	10/31/2003	0.0140		0.0140	0.0660		0.0660	ND	0.0094	0.0047	0.079		0.0790	12.00		12.0000	1,900		1,900	37.7		37.7
MW 109	4.5	Davis Property	10/31/2003	ND	0.0029	0.0015	0.0160		0.0160	ND	0.0046	0.0023	0.059		0.0590	12.00		12.0000	2,100		2,100	76.5		76.5
HBK01-2P-02	0.5	Davis Property	8/28/2001	ND	0.0183	0.0092	ND	0.0734	0.0367	ND	0.0734	0.0367	ND	0.0734	0.0367	ND	3.67	1.8350	2,520		2,520			
SB 42	2.5	Davis Property	7/5/1992																14,524		14,524			
				average		0.0161			0.0617			0.0142			0.0798			12.2			3,510.5			30
				std. dev.		0.0259			0.0850			0.0149			0.0947			18.2			4,682.4			28.6
				count		7			7			7			7			7			8.0			5
				std. dev. of mean		0.0098			0.0321			0.0056			0.0358			6.9			1,655.5			12.8
				95%UCL		0.0356			0.1259			0.0255			0.1514			26.0			6,821.5			55.6
				maximum		0.0740			0.2500			0.0367			0.2900			52.0			14,524.0			76.5

TABLE A2C
2003 BTEX, GRO & DRO Groundwater Concentrations, Davis Property Site, Strawberry Point

Test Hole Number & Depth (ft. bgs)	Depth (ft. bgs)	Location	Date Collected:	Benzene			Toluene			Ethylbenzene			Xylenes			Gasoline Range Organics			Diesel Range Organics			Residual Range Organics			
				Lab Result ug/L	Detection Limit mg/L	Stat Value ug/L	Lab Result ug/L	Detection Limit mg/L	Stat Value ug/L	Lab Result ug/L	Detection Limit mg/L	Stat Value ug/L	Lab Result ug/L	Detection Limit mg/L	Stat Value ug/L	Lab Result ug/L	Detection Limit mg/L	Stat Value ug/L	Lab Result mg/L	Detection Limit mg/L	Stat Value mg/L	Lab Result mg/L	Detection Limit mg/L	Stat Value ug/L	
MW 109	NA	Davis Property	11/06/2003	ND	0.1000	0.0500	ND	0.4800	0.2400	ND	0.1200	0.0600	ND	1.000	0.5000	ND	14.00	7.0000	2.700	2.700	2.70	0.05		0.05	
MW 115	NA	Davis Property	11/06/2003	ND	0.0900	0.0450	ND	0.3500	0.1750	ND	0.1600	0.0800	ND	0.790	0.3950	ND	6.40	3.2000	ND	0.028	0.01	ND	0.028	0.014	
				average																					
				std. dev.																					
				count																					
				std. dev. of mean																					
				95%UCL																					
				maximum		0.0500			0.2400			0.0600			0.5000			7.0			2.7			0.05	

TABLE A3A

TPH and DRO Soil Concentrations Outside the Generator and Shop Building NAPL Contaminated Soil Source Area, FAA Strawberry Point Station

Primary Location Description	Revised or Alternate Location Description	Inside or Outside Source Area	Sampling Date	Sample Depth (ft)	TPH (mg/kg)	DRO (mg/kg)	Average of TPH & DRO (mg/kg)
SB7		Outside	July-92	9	7.5	70	
SB9		Outside	July-92	10	0.94		
SB10		Outside	July-92	7	8.7		
SB10		Outside	July-92	10	3		
SB17		Outside	July-92	3	3.7		
SB17		Outside	July-92	5	8.9		
SB17		Outside	July-92	8	3.5		
SB18		Outside	July-92	9.5	39		
SB21		Outside	July-92	6.5	1.9		
SB21		Outside	July-92	9	38		
SB23		Outside	July-92	1	4.8		
SB23		Outside	July-92	2.5	ND (<10)		
SB26		Outside	July-92	1	1.7		
SB26		Outside	July-92	2.5	ND (<10)		
SB34		Outside	July-92	7	4.4		
SB35		Outside	July-92	8	2.7		
SB38		Outside	July-92	8	11		
SB59		Outside	July-92	3	24		
SB59		Outside	July-92	8	20		
SB61		Outside	July-92	6	11		
MW1		Outside	July-92	3	6.8	ND (<10)	
MW1		Outside	July-92	10	4.7	ND (<10)	
MW2		Outside	July-92	3	3.3		
MW2		Outside	July-92	10	4.2		
MW3		Outside	July-92	3	8.4	ND (<10)	
MW3		Outside	July-92	10	7.3	ND (<10)	
SB7		Outside	July-92	5	ND (<10)		
SB9		Outside	July-92	7		ND (<10)	
SB10		Outside	July-92	5		ND (<10)	
SB10		Outside	July-92	10		ND (<10)	
SB15		Outside	July-92	7		ND (<10)	
SB16		Outside	July-92	8		ND (<10)	
SB16		Outside	July-92	9.5		ND (<10)	
SB17		Outside	July-92	3		ND (<10)	
SB17		Outside	July-92	5		ND (<10)	
SB17		Outside	July-92	8		ND (<10)	
SB18		Outside	July-92	9.5		ND (<10)	
SB18		Outside	July-92	10.5		ND (<10)	
SB18		Outside	July-92	20		ND (<10)	
SB21		Outside	July-92	9		ND (<10)	
SB22		Outside	July-92	2.5		ND (<10)	
SB22		Outside	July-92	5		ND (<10)	
SB22		Outside	July-92	7		ND (<10)	
SB34		Outside	July-92	4		ND (<10)	
SB34		Outside	July-92	5.5		ND (<10)	
SB34		Outside	July-92	10.5		ND (<10)	
SB39		Outside	July-92	11		ND (<10)	
SB59		Outside	July-92	6		ND (<10)	
SB59		Outside	July-92	11		ND (<10)	
SB60		Outside	July-92	8		ND (<10)	
SB60		Outside	July-92	11		ND (<10)	
SB61		Outside	July-92	8		ND (<10)	
SB61		Outside	July-92	11		ND (<10)	

TABLE A3B

TPH and DRO Soil Concentrations Inside the Generator and Shop Building NAPL Contaminated Soil Source Area, FAA
Strawberry Point Station

Primary Location Description	Revised or Alternate Location Description	Inside or Outside Source Area	Sampling Date	Sample Depth (ft)	TPH (mg/kg)	DRO (mg/kg)	Average of TPH & DRO (mg/kg)
MW-4		Inside	7/1/1992	5	15,835	14,000	14,918
MW-4		Inside	7/2/1992	10		1,300	1,300
MW-5		Inside	7/3/1992	5	15,422	14,000	14,711
MW-5		Inside	7/4/1992	8.5	14,929	16,000	15,465
MW-6		Inside	7/5/1992	5		11,000	11,000
MW-6		Inside	7/6/1992	9		4,100	4,100
SB-8		Inside	7/7/1992	5		19,000	19,000
SB-13		Inside	7/2/1992	6	30,398		30,398
MW-19		Inside	7/2/1992	8 ²		7,950	7,950
MW-33		Inside	7/4/1992	5	13,594		13,594
MW-33		Inside	7/4/1992	8.5	33,332	11,000	22,166
MW-33		Inside	7/4/1992	11		4,300	4,300
SB-36		Inside	7/4/1992	6		2,500	2,500
SB-36		Inside	7/4/1992	8	15,077		15,077
SB-36		Inside	7/4/1992	11 ²		9,700	9,700
SB-37		Inside	7/4/1992	8	5,671	5,000	5,336
SB-37		Inside	7/4/1992	11		10,000	10,000
SB-41		Inside	7/4/1992	6	30,987		30,987
SB-42		Inside	7/5/1992	2.5	14,524		14,524
SB-55		Inside	7/6/1992	5	22,500		22,500
SB-55		Inside	7/6/1992	11	13,756		13,756
SB-56		Inside	7/6/1992	8	8,342		8,342
SB-57		Inside	7/9/1992	6	22,886		22,886
SB-57		Inside	7/9/1992	11		15,000	15,000
SB-58		Inside	7/7/1992	6	8,308		8,308
SB-58		Inside	7/7/1992	8	25,399		25,399
SB-58		Inside	7/7/1992	11		20,000	20,000
SB-62 (MW)		Inside	7/9/1992	8		3,000	3,000
SB-63		Inside	7/10/1992	8		20,000	20,000
TH-9	SW-9	Inside	6/3/1994	6		17,500	17,500
TH-11	SW-12	Inside	6/4/1994	5.5		23,700	23,700
TH-16	SW-16	Inside	6/2/1994	10.5 ²		11,250	11,250
TH-24		Inside	5/31/1994	6		2,600	2,600
TH-29	SW-27	Inside	5/31/1994	6		7,300	7,300
TH-33	MW-1	Inside	6/1/1994	10		2,000	2,000
TH-36	SW-18	Inside	6/3/1994	6		1,500	1,500
MW-4		Inside	11/14/1998	6.5		4000	4,000
MW-5		Inside	11/14/1998	6.5		12000	12,000
MW-5		Inside	11/14/1998	8.5		8700	8,700
MW-6		Inside	11/14/1998	5.5		4500	4,500
MW-6		Inside	11/14/1998	9		7100	7,100
SB-8		Inside	11/14/1998	5.5		14000	14,000
SB-13		Inside	11/14/1998	6		12000	12,000
MW-19		Inside	11/14/1998	8		5400	5,400
MW-33		Inside	11/14/1998	5.5		220	220
MW-33		Inside	11/14/1998	8.5		7300	7,300
SB-36		Inside	11/14/1998	8		240	240
SB-41		Inside	11/14/1998	6 ²		8950	8,950
SB-55		Inside	11/14/1998	5.5		3500	3,500
SB-55		Inside	11/14/1998	10		9400	9,400
SB-57		Inside	11/14/1998	6		11000	11,000
SB-57		Inside	11/14/1998	10		19000	19,000
SB-58		Inside	11/14/1998	6		2800	2,800
SB-58		Inside	11/14/1998	8		6400	6,400
SB-58		Inside	11/14/1998	10		9100	9,100
SB-63		Inside	11/14/1998	8		10000	10,000
TH-9	SW-9	Inside	11/14/1998	6.5 ²		650	650
TH-11	SW-12	Inside	11/14/1998	6 ²		14000	14,000
TH-16	SW-16	Inside	11/14/1998	10		12000	12,000
SSW1	Southwest	Inside	11/14/1998	6		2200	2,200

TABLE A3B continued

TPH and DRO Soil Concentrations Inside the Generator and Shop Building NAPL Contaminated Soil Source Area, FAA Strawberry Point Station

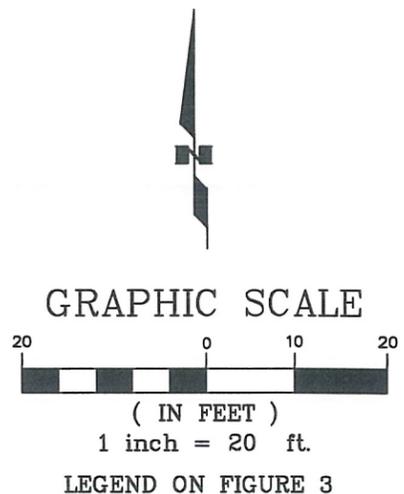
Primary Location Description	Revised or Alternate Location Description	Inside or Outside Source Area	Sampling Date	Sample Depth (ft)	TPH (mg/kg)	DRO (mg/kg)	Average of TPH & DRO (mg/kg)
SSW2	Southeast	Inside	11/14/1998	7.5		320	320
SSW3	Center	Inside	11/14/1998	7.5		2,800	2,800
SSW4	North	Inside	11/14/1998	9		720	720
SW2 NE		Inside	11/14/1998	9.5		4,900	4,900
SW31 NW		Inside	11/14/1998	9.5		13,000	13,000
MW-5		Inside	6/2/2000	6.5		2,200	2,200
SB-8		Inside	6/2/2000	6		9,200	9,200
SB-13		Inside	6/2/2000	6.5		390	390
SB-57		Inside	6/2/2000	8		17,000	17,000
SB-57		Inside	6/2/2000	10		10,000	10,000
TH-11	SW-12	Inside	6/2/2000	6		3,800	3,800
TH-16	SW-16	Inside	6/2/2000	10		9,000	9,000
SW31 NW		Inside	6/2/2000	9.5		10,000	10,000
MW-4		Inside	10/28/2003	6.5		7,400	7,400
MW-5		Inside	10/28/2003	8.5		2,800	2,800
MW-33		Inside	10/28/2003	8		840	840
SB-55	MW 106	Inside	10/28/2003	10		5,400	5,400
SB-56	TH 101	Inside	10/28/2003	9.5		1,800	1,800
SB-57	TH 102	Inside	10/28/2003	11		12,000	12,000
SB-58	TH 103	Inside	10/28/2003	9		5,800	5,800

TABLE A4

Soil Source Area Characterization, Shop & Generator Building Site, Strawberry Point

Test Hole Number & Depth (ft. bgs)	Depth (ft. bgs)	Location	Date Collected:	Benzene			Toluene			Ethylbenzene			Xylenes			Gasoline Range Organics			Diesel Range Organics			Residual Range Organics		
				Lab Result mg/kg	Detection Limit mg/kg	Stat Value mg/kg	Lab Result mg/kg	Detection Limit mg/kg	Stat Value mg/kg	Lab Result mg/kg	Detection Limit mg/kg	Stat Value mg/kg	Lab Result mg/kg	Detection Limit mg/kg	Stat Value mg/kg	Lab Result mg/kg	Detection Limit mg/kg	Stat Value mg/kg	Lab Result mg/kg	Lab Result mg/kg	Stat Value mg/kg	Lab Result mg/kg	Lab Result mg/kg	Stat Value mg/kg
TH 103	9	Shop & Gen Bldg	10/28/2003	ND	0.0047	0.0024	ND	0.0180	0.0090	ND	0.0065	0.0033	ND	0.023	0.0115	22.0		22.0	5,800		5,800	218		218
TH 102	11	Shop & Gen Bldg	10/28/2003	ND	0.0054	0.0027	ND	0.0240	0.0120	0.0340	0.0027	0.0340	0.770	0.0120	0.7700	70.0		70.0	12,000		12,000	676		676
TH 101	9.5	Shop & Gen Bldg	10/28/2003	ND	0.0019	0.0010	0.0075		0.0075	ND	0.0014	0.0007	0.020		0.0200	3.1		3.1	1,800		1,800	26.4		26.4
SB 13	7	Shop & Gen Bldg	10/28/2003	ND	0.0030	0.0015	ND	0.0094	0.0047	ND	0.0027	0.0014	0.026		0.0260	ND	0.48	0.24	42		42	148		148
MW 5	8.5	Shop & Gen Bldg	10/28/2003	1.4000		1.4000	2.7000		2.7000	0.1800		0.1800	1.000		1.0000	32.0		32.0	2,800		2,800	268.3		268.3
MW 4	6.5	Shop & Gen Bldg	10/28/2003	0.0100		0.0100	0.0730		0.0730	0.0150		0.0150	0.076		0.0760	ND	0.52	0.26	7,400		7,400	104.7		104.7
MW 33	8	Shop & Gen Bldg	10/28/2003	ND	0.0200	0.0100	0.0640		0.0640	ND	0.0090	0.0045	0.066		0.0660	6.6		6.6	840		840	258.94		258.94
MW 106	10	Shop & Gen Bldg	10/28/2003	ND	0.0110	0.0055	0.0600		0.0600	0.0360		0.0360	0.270		0.2700	78.0		78.0	5,400		5,400	23.4		23.4
MW-5 6.5	6.5	Shop & Gen Bldg	6/2/2000																2,200		2,200			
SB-8	6	Shop & Gen Bldg	6/2/2000																9,200		9,200			
SB-13	6.5	Shop & Gen Bldg	6/2/2000																390		390			
SB-57	8	Shop & Gen Bldg	6/2/2000																17,000		17,000			
SB-57	10	Shop & Gen Bldg	6/2/2000																1,000		1,000			
TH-11/ SW-12	6	Shop & Gen Bldg	6/2/2000																3,800		3,800			
TH-16/ SW-16	10	Shop & Gen Bldg	6/2/2000																9,000		9,000			
SW31 NW	9.5	Shop & Gen Bldg	6/2/2000																10,000		10,000			
				average		0.7050			0.5809			0.0663			0.3183			35.3			5,542			215
				std. dev.		0.9829			1.1849			0.0764			0.4016			31.9			4,879			209.2
				count		2			5			4			7			6			16			8
				std. dev. of mean		0.6950			0.5299			0.0382			0.1518			13.0			1,220			73.9
				95%UCL		2.0950			1.6407			0.1427			0.6219			61.3			7,981			363.4
				maximum		1.4000			2.7000			0.1800			1.0000			78.0			17,000			676.0

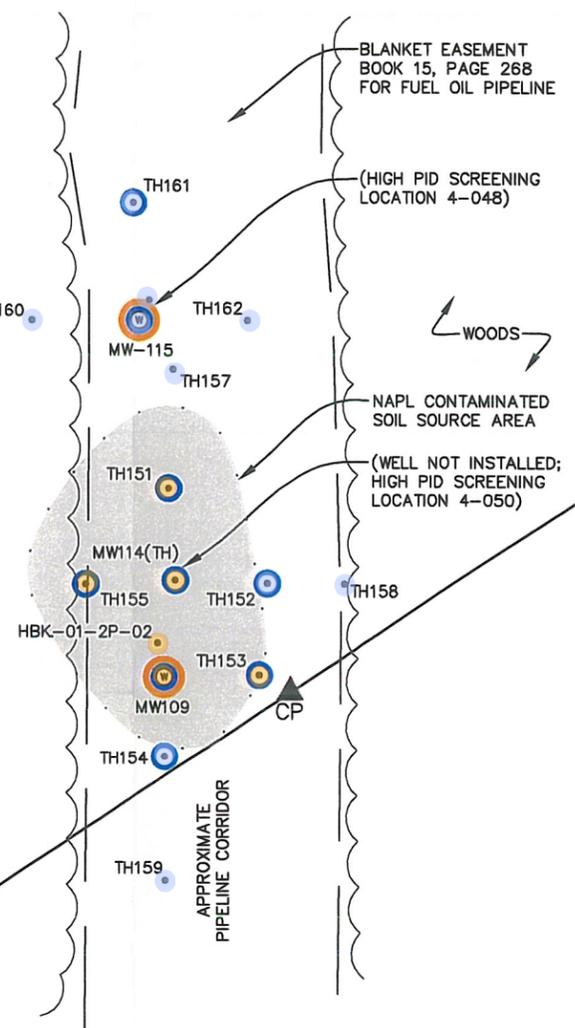
For test results below the method detection limit a value of 1/2 the detection limit was used as the statistical value.



BLOCK 1
RENNER SUBDIVISION
PLAT NO. 2000-2

13
RICHARD S. DAVIS & DAGMAR J. DAVIS

10



Davis Property, Renner Subdivision Lot 13 Soil Screening Data and Soil DRO & GRO Results

Test Hole Number & Depth (ft. bgs)	Location	Date Collected:	PID Reading		GRO		DRO	
			ppm	Lab Result mg/kg	Lab qualifier	Lab Result mg/kg	Lab qualifier	
HBK01-2P-02	Davis Prop.	8/28/2001					2,520	
High PID screening location 4-048	Davis Prop.	pre 2003	63					
High PID screening location 4-050	Davis Prop.	pre 2003	281					
MW109 4.5	Davis Prop.	10/31/2003		12.00			2,100.0	
MW109 5	Davis Prop.	10/31/2003	190					
MW109 6	Davis Prop.	10/31/2003	54.7	12.00			1,900.0	
MW114 4.5 (TH)	Davis Prop.	10/31/2003		0.40	ND		250.0	
MW114 5 (TH)	Davis Prop.	10/31/2003	24.1					
MW114 6 (TH)	Davis Prop.	10/31/2003	43.5	0.99	ND		690.0	
TH151 5	Davis Prop.	10/31/2003	132/315					
TH151 6.5	Davis Prop.	10/31/2003		52.00			5,000.0	
TH151 7	Davis Prop.	10/31/2003	151					
TH152 5	Davis Prop.	10/31/2003	8.6					
TH152 6	Davis Prop.	10/31/2003		0.37	ND		4.2	ND
TH152 7	Davis Prop.	10/31/2003	4.6					
TH153 5	Davis Prop.	10/31/2003	68.9/108					
TH153 6	Davis Prop.	10/31/2003		0.91	ND		28.0	
TH153 7	Davis Prop.	10/31/2003	23.4					
TH154 5	Davis Prop.	10/31/2003	10.3/12.7					
TH154 6	Davis Prop.	10/31/2003		0.24	ND		13.0	
TH154 6.5	Davis Prop.	10/31/2003	11.3					
TH155 5	Davis Prop.	10/31/2003	200/296					
TH155 6.5	Davis Prop.	10/31/2003	79.2	6.40			1,100.0	
TH156 6.5	Davis Prop.	11/4/2003	0					
TH157 6.5	Davis Prop.	11/4/2003	0					
TH158 6.5	Davis Prop.	11/4/2003	0					
TH159 6.5	Davis Prop.	11/4/2003	0					
TH160 7	Davis Prop.	11/4/2003	0					
TH161 7	Davis Prop.	11/4/2003	0	0.59	ND		1.7	ND
TH162 7	Davis Prop.	11/4/2003	0					
MW115 7	Davis Prop.	11/4/2003	0	0.17	ND		1.9	ND
TH163 (MW)	Davis Prop.	11/4/2003	0					

Numerous other PID readings from the area (collected during pipeline decommissioning) had low or 0 ppm readings.

SECTION 15
CHUGACH NATIONAL FOREST
PENDING SELECTION BY STATE OF ALASKA
THE EYAK CORPORATION, AND CHUGACH ALASKA
CORPORATION PER BLM MASTER TITLE PLAT

LOCATED WITHIN T17S, R5W, C.R.M.
CORDOVA RECORDING DISTRICT

**FAA SITE STRAWBERRY POINT
HINCHINBROOK ISLAND, ALASKA**

DAVIS PROPERTY

DATE: 9-24-04

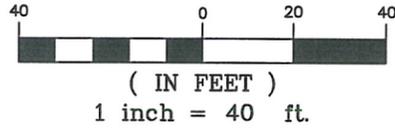
FIGURE A1

GOVT. LOT 10
SECTION 16
THE EYAK CORPORATION IC 1772
CHUGACH ALASKA CORPORATION IC 1773





GRAPHIC SCALE

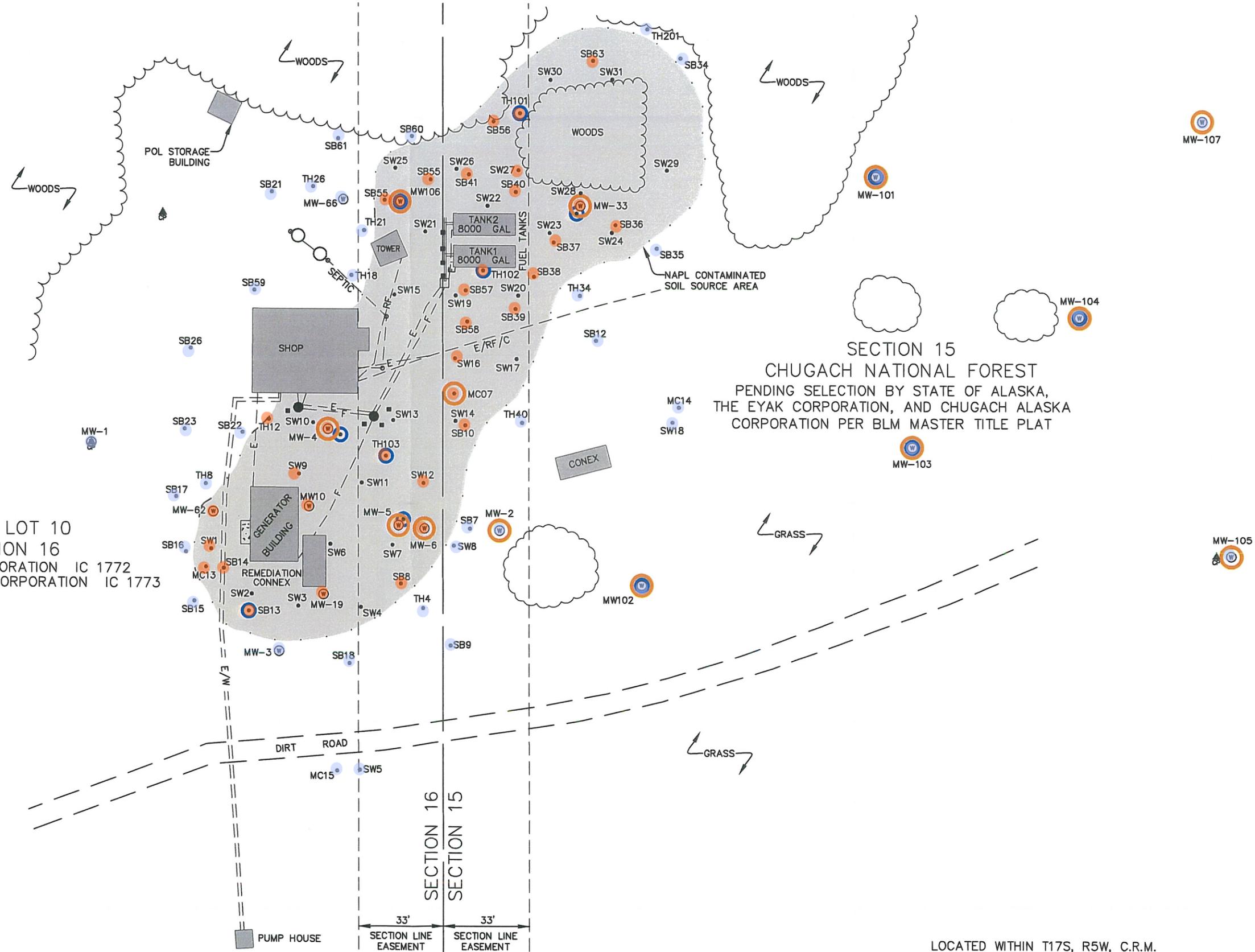


DUMP SITE
MW-207

GOVT. LOT 10
SECTION 16
THE EYAK CORPORATION IC 1772
CHUGACH ALASKA CORPORATION IC 1773

SECTION 15
CHUGACH NATIONAL FOREST
PENDING SELECTION BY STATE OF ALASKA,
THE EYAK CORPORATION, AND CHUGACH ALASKA
CORPORATION PER BLM MASTER TITLE PLAT

- LEGEND**
- ⊕ Existing Groundwater Monitoring Well
 - SB, TH Previous Soil Boring or Test Hole
 - SW Previous Air Sparging Well
 - HBK, BES Soil Grab Sample Location
 - 3 inch diam. PVC Septic Vent
 - 42 inch diam. Vert. CMP Fuel Valve Box
 - 60 inch diam. Vert. CMP above Septic Tank
 - ⊕ Aluminum Cap Monument
 - ▲ Survey Control Monument
 - E Underground Electric
 - RF Underground RF Cable
 - F Underground Fuel Line
 - W Underground Water
 - C Underground Communication Line
 - Bollard Guard Post
 - ⊕ Soil Sampling Location (2003)
 - ⊕ Water Sampling Location (2003)



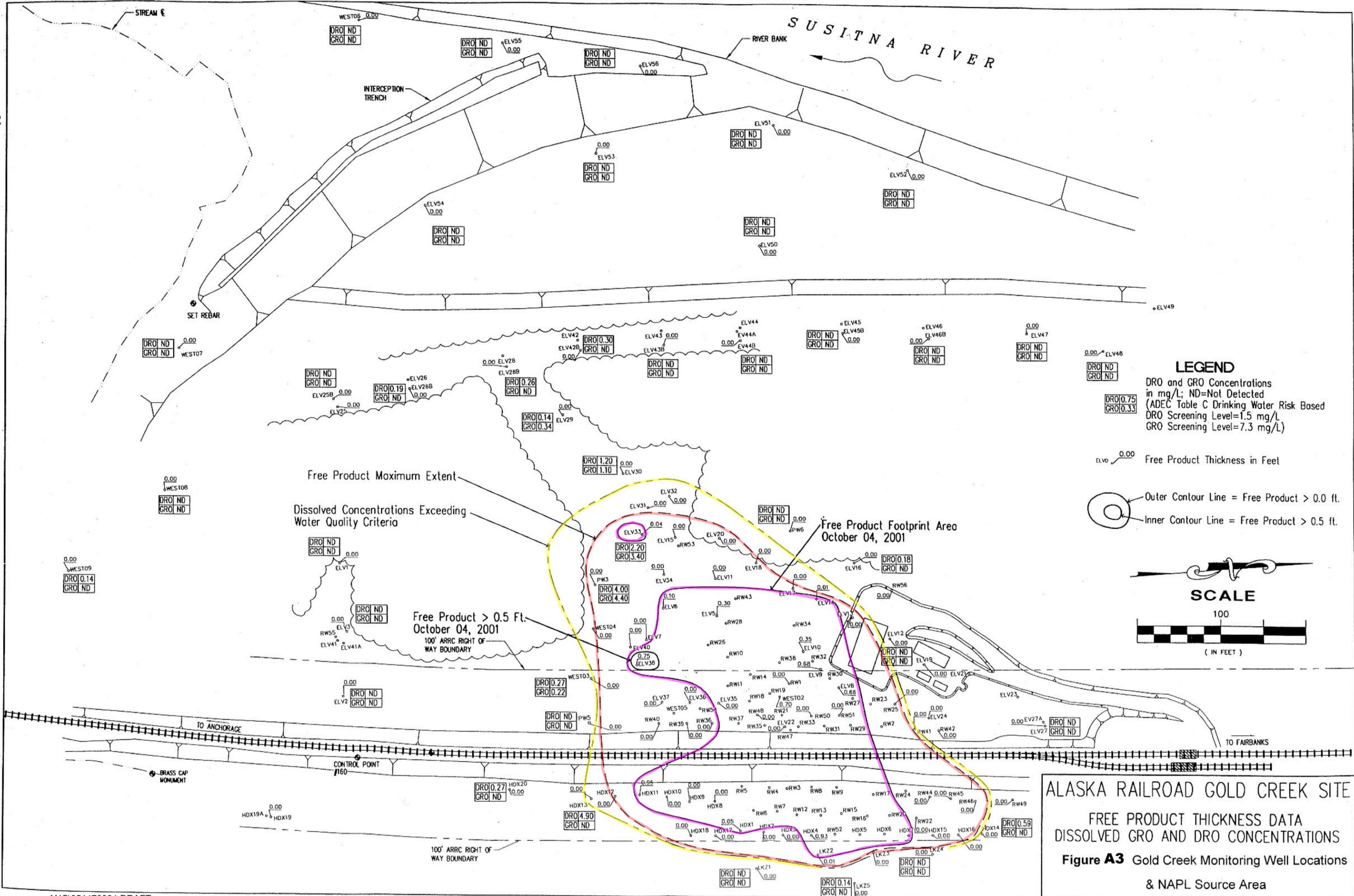
LOCATED WITHIN T17S, R5W, C.R.M.
CORDOVA RECORDING DISTRICT

FAA SITE STRAWBERRY POINT HINCHINBROOK ISLAND, ALASKA

SHOP AND GENERATOR BUILDING

DATE: 9-24-04

FIGURE A2



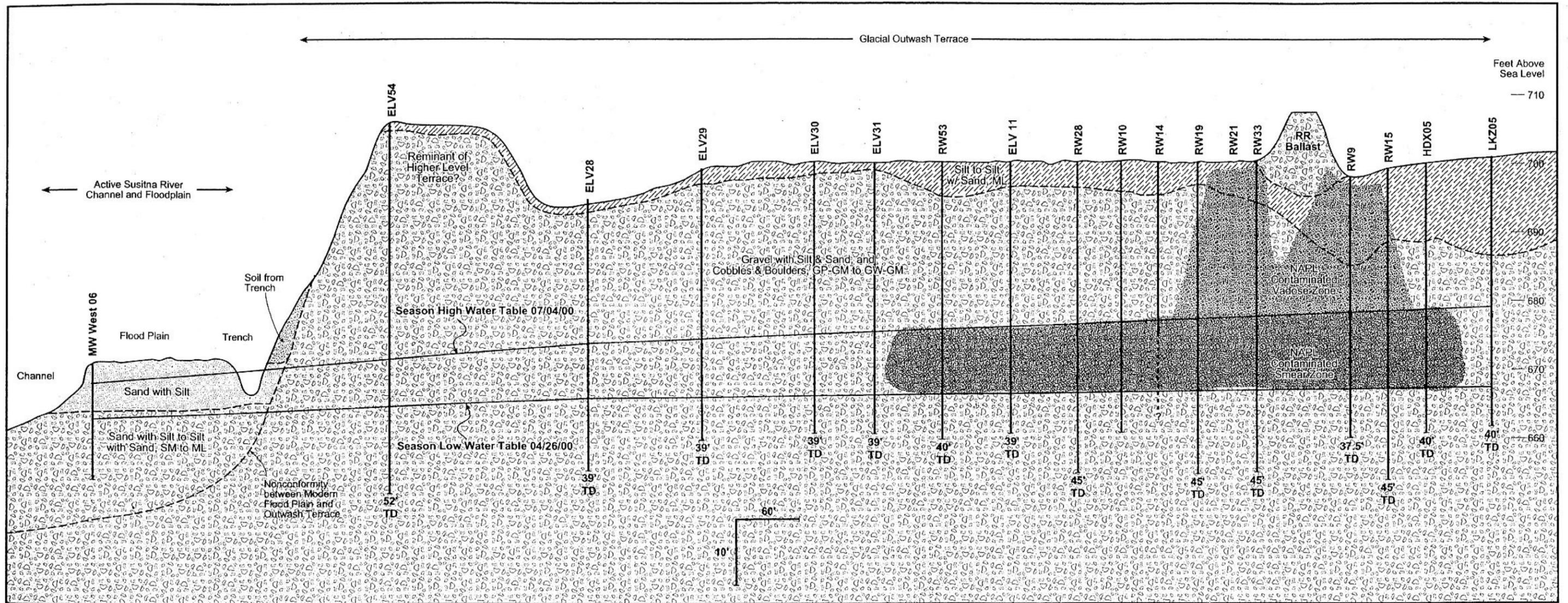
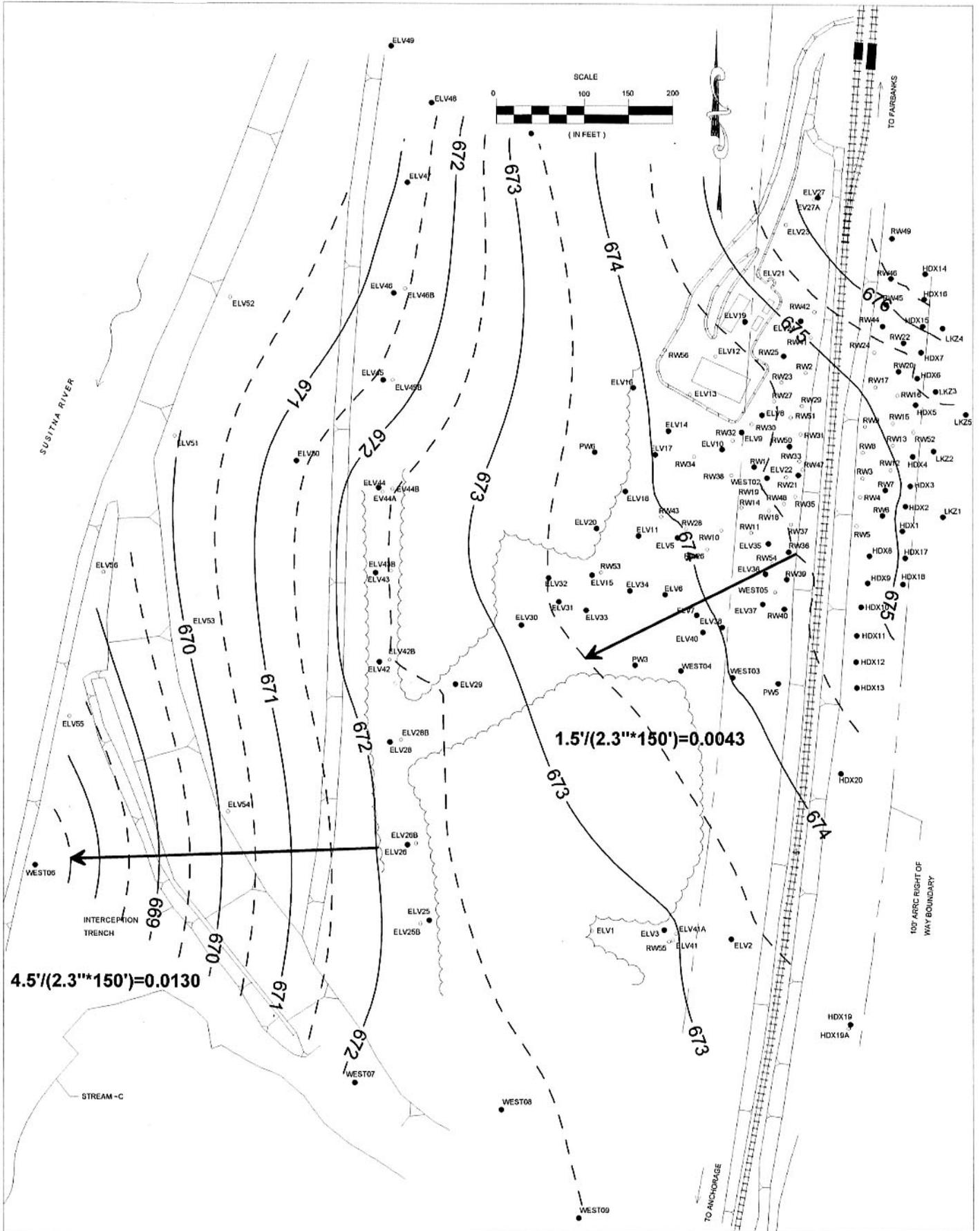


Figure A4 Gold Creek Cross-Section Showing the NAPL Source Area and Seasonal Groundwater Fluctuation

Figure A5 Groundwater Contours 6-23-01, ARRC Gold Creek Site



Appendix B
Fixed Mixing Depth Dilution-Attenuation Factor

Fixed Mixing Depth Dilution Attenuation Factor

B1 Introduction

Dissolved-phase fuel hydrocarbons being transported by groundwater are subject to dilution and attenuation processes as they move through the soil environment. The degree of contaminant concentration reduction at any point downgradient of the source area as a result of the combined effect of dilution and attenuation may be referred to as the “dilution-attenuation factor” (DAF), which is defined as follows:

$$\text{DAF} = \frac{\text{concentration in source area}}{\text{concentration at downgradient location of interest}}$$

As defined above, DAFs have values equal to or greater than one, and larger DAF values indicate greater dilution and attenuation. Dilution and attenuation factors must be defined and/or measured at a point or over an interval.

The Alaska Department of Environmental Conservation (ADEC) uses a DAF in the assessment of potential risk through a hypothetical migration-to-groundwater pathway. The migration-to-groundwater calculations evaluate whether the soil concentrations are likely to cause groundwater contamination above a maximum contaminant level (MCL) or a groundwater-ingestion risk-based concentration, over an interval of aquifer that may be used as a source of drinking water. According to the ADEC regulations (Title 18, Chapter 75, of *Alaska Administrative Code* [AAC]) to close a contaminated site, the site must meet the migration-to-groundwater criteria. As documented in the ADEC guidance document on cumulative risk (2008), the migration-to-groundwater risk calculation, which incorporates the DAF, is not used in the calculation of cumulative risk—rather, measured groundwater concentrations are used to assess cumulative risk. If the measured groundwater concentrations and the groundwater concentrations predicted by using the DAF do not agree, then the true DAF at the site of interest is likely different from the DAF used in the predictive calculation.

Use of a DAF to assess soil cleanup levels requires that the DAF is mathematically formulated to address the compliance point or compliance zone of interest, and that the DAF calculation represents the site conditions and the physical processes occurring at the site. DAFs are useful because they relate the dissolved concentration in the source area to the dissolved concentration at downgradient potential receptor locations. DAFs can be used in “forward calculations” to assess the risk at some downgradient location resulting from a known source area concentration, or they can be used in “backward calculations” to assess the dissolved concentration in a source area that presents an acceptable risk at a downgradient receptor location. When making backward calculations, if the source area does not contain nonaqueous phase liquid (NAPL), then the source area dissolved concentration may be related to a source area soil concentration that may be considered the soil cleanup level. If the source area does contain NAPL, then the source area concentration may be used to calculate the allowable mole

fraction of the compound of interest in the NAPL (but it cannot be used to back calculate a soil cleanup level).

B2 DAF Equation Used in the Hydrocarbon Risk Calculator

The dilution-attenuation factor in the hydrocarbon risk calculator (HRC) uses a Summers mixing box model calculation that assumes a fixed mixing zone depth; accounts for the presence of NAPL in the vadose, seasonally saturated, and/or saturated zones; and allows representative biodegradation in the saturated zone.

Figure B1 shows the conceptual site conditions associated with the DAF calculation. The conceptual site conditions include the following:

- A contaminated soil source area that may be in one or more of the following: the vadose zone, seasonally saturated zone, and saturated zone. The position of the contaminated source area soils relative to the water table is defined by model input values that include the depth to the top and bottom of the contaminated soil source, length of the source, and depth to the annual-high and annual-low water table.
- Precipitation infiltration occurs across the site and provides recharge to the water table aquifer. Infiltration that reaches the water table is displaced downward by downgradient infiltration, as indicated by the particle path lines shown in the figure. The angle of downward displacement is a function of the hydraulic conductivity, gradient and infiltration rate used as input to the model.
- The mixing zone or migration-to-groundwater compliance zone is represented by a hypothetical drinking water well located at the downgradient edge of the source area, as shown in Figure 1. (This location for the fixed mixing zone is the most conservative.) The mixing zone or hypothetical drinking water well screen has a fixed depth extending 18 feet below the seasonal low water table (or to the bottom of the water table aquifer, if the water table aquifer is less than 18 feet thick). Because the mixing zone depth is fixed, the DAF used in the HRC may be described as a fixed mixing depth (FMD) DAF. (Use of the FMD DAF is in contrast to use of the variable mixing depth DAF prior to 2008.)

As shown in Figure 1, groundwater entering this fixed mixing zone or hypothetical drinking water well may conceptually follow three flow paths designated Q1, Q2, and Q3 in Figure 1. These flow paths are described as follows:

- Q1 represents groundwater that flows from the submerged portion of the source directly into the mixing zone. Hydrocarbon concentrations in groundwater that flows from the saturated NAPL source zone directly into the mixing zone will be in equilibrium with the NAPL source.
- Q2 represents groundwater derived from infiltrating precipitation that flows from the bottom of the vadose zone or saturated portions of the NAPL source area. Hydrocarbon concentrations in groundwater that passes through a portion of the source zone but is deflected out the bottom of the source zone by infiltrating precipitation will be in equilibrium with the source zone soils as it leaves the source zone, but will be subject to attenuation (biodegradation) below the source as it travels to the mixing zone at the

downgradient edge of the source area. Given that biodegradation may be described using a first-order rate function, the groundwater that emanates from the upgradient portions of the source zone follows a longer flow path and takes a longer period of time to reach the mixing zone; therefore this groundwater will experience more biodegradation.

- Q3 represents groundwater that flows beneath the source zone without being significantly affected by the source. Groundwater that flows through the fixed-depth mixing zone, but does not encounter contaminated soils is considered to be uncontaminated (dispersion is discussed below).

The general DAF model is based on a mass balance as follows:

$$DAF = C_o / C_a$$

Where: C_o = dissolved concentration in equilibrium with NAPL

C_a = average concentration in fixed mixing zone

$$C_a = ((Q_1 * C_o) + (Q_2 * C_i)) / Q_t$$

Where: Q_1 = groundwater flow through saturated source zone = hydraulic conductivity * gradient * source saturated thickness (up to the limit of the mixing zone depth)

C_o = dissolved concentration in equilibrium with NAPL

Q_2 = flow from bottom of source zone that passes through the mixing zone = infiltration rate * source length (up to the limit of $Q_t - Q_1$)

C_i = concentration at mixing zone location of water emanating from the bottom of source area (accounting for biodegradation) = $C_o * e^{-kt}$, where k = first order biodegradation rate constant and t = compound travel time = (travel distance / advective velocity) * retardation factor

Q_t = total flow through fixed-depth mixing zone = hydraulic conductivity * gradient * fixed mixing zone depth = $Q_1 + Q_2 + Q_3$

In the HRC DAF calculation, the flow described above as Q_2 , which emanates from the bottom of the NAPL source and flows through the fixed-depth mixing zone, is subdivided into 10 flow tubes. The groundwater travel time and attenuated concentration for each flow tube is calculated, assuming first order biodegradation. In addition, a DAF for the low-water-table condition and the high-water-table condition are calculated and the more conservative of the two values (lower DAF value) is used to assess whether the migration-to-groundwater criteria has been met. If the source is entirely in the vadose zone, the low-water DAF will be lower than the high-water DAF, and if the source has penetrated to the smear zone, then the DAF will be lower during periods of high groundwater when more of the NAPL-contaminated soil source zone is submerged.

To simplify calculations, the impact of hydrodynamic dispersion is not considered in the calculation of the DAF. This approach is considered to be conservative. Hydrodynamic dispersion would tend to cause dissolved-phase contaminants carried out of the bottom of the source area in the Q_2 zone to mix with the Q_3 zone, which would tend to increase the

concentration in the Q3 zone and reduce the concentration in Q2 zone, but there would be no net effect on the mass of dissolved-phase contaminants leaving the source zone. If the groundwater upgradient of the site and in Q3 carried dissolved oxygen, then hydrodynamic dispersion would tend to allow aerobic biodegradation of dissolved-phase contaminants in Q3 and potentially in Q2, which would reduce the mass of contaminants reaching the mixing zone beyond that accounted for by first-order biodegradation. Not considering the effects of aerobic biodegradation, if the depth of hydrodynamic dispersion is less than the depth of the mixing zone, then hydrodynamic dispersion would tend to have no net effect on the calculated DAF; if the depth of hydrodynamic dispersion is greater than the depth of the mixing zone, then the calculated DAF would be conservative.

The ADEC infiltration assumption is that infiltration to the water table is 20 percent of precipitation. The true infiltration rate is a complex function of conditions such as soil texture, soil permeability, slope, surface cover, precipitation amount and intensity, and frozen ground conditions during precipitation and snow melt events. Several models relating infiltration to soil texture have been developed and may provide better infiltration estimates than the 20 percent of precipitation default assumption, particularly in fine-grained soils such as dense silts and clays. For this reason, the infiltration rate is a direct input parameter to the DAF calculation as follows: the precipitation rate is entered into the model, the default infiltration rate is calculated, and then the default infiltration rate is entered or a site-specific infiltration rate is entered. The site-specific infiltration rate may be based on published reports for the area, measured directly, or calculated using a different infiltration-precipitation model.

B3 Calculation of Half-Lives, First-order Rate Constants, and Retardation Factors

In the HRC DAF, the dissolved-phase contaminants that flow or are advected from the bottom of the NAPL-contaminated source are subject to biodegradation as they travel to the mixing zone at the downgradient edge of the source (Figure 1). In general, biodegradation in and downgradient of the source is assumed to be anaerobic, because oxygen in the groundwater upgradient of the site would likely have been consumed in an instantaneous reaction at the upgradient edge of the source. The HRC DAF assumes that biodegradation in the anaerobic, downgradient, dissolved-phase plume may typically be described using a first-order decay rate in which the biodegradation rate is a function of the dissolved-phase concentration. The exponential function is described below:

$$C_i = C_o * e^{-kt}$$

Where: C_i = dissolved-phase concentration at the mixing zone

C_o = dissolved-phase concentration in equilibrium with the source zone

k = first-order biodegradation rate constant = 0.693/ half-life

t = compound travel time from the source to the mixing zone = (travel distance/ advective velocity) * R

R = retardation factor = $(1 + (\text{bulk density}/\text{porosity}) * k_{oc} * f_{oc})$

k_{oc} = organic carbon partitioning coefficient

f_{oc} = fraction of organic carbon

In the above description, the first-order rate constant is related to a “dissolved-phase half-life,” which is the time required for half the dissolved-phase concentration to biodegrade. The first-order rate constant used as input to the HRC is best developed from site-specific data, but can also be estimated from published literature. The calculation of a site-specific, first-order rate constant uses dissolved-phase concentrations collected in the NAPL source area and along the centerline of downgradient plume. The dissolved-phase concentrations are plotted against distance downgradient of the source (typically in a semi log plot), and the slope of the line formed by the data is used to calculate the rate constant. Several options are available to help with these calculations, including the following:

- The BIOSCREEN model (distributed free of charge by the EPA) may be used by entering the site-specific hydraulic conductivity, gradient, porosity, bulk density, source width, thickness, plume length, and f_{oc} data, and then iteratively adjusting the half-life or rate constant values to match the field data. The half-life or rate constant calculated using this approach may be considered a “biodegradation half-life or rate constant” that accounts for dispersion and retardation.
- A spreadsheet has been developed to calculate the compound half-life and rate constants using the method of Buscheck and Alcantar (1995). Data input to the spreadsheet include concentrations in the source area and in monitoring wells along the centerline of the downgradient dissolved-phase plume, the monitoring well distances downgradient of the NAPL source area, and information on the advective and retarded velocities. The half-life or rate constant calculated using this approach may be considered a “biodegradation half-life or rate constant” that accounts for longitudinal dispersion and retardation (but does not account for lateral or vertical dispersion). Note that for relatively short dissolved phase and plumes from relatively wide and thick sources, the attenuation caused by lateral and vertical dispersion is likely small compared to attenuation caused by biodegradation.

The use of a first-order decay model to characterize the attenuation of occurring in the groundwater emanating from the bottom of the source area is interpreted to be significantly more representative than assuming a constant attenuation factor for all compounds and promotes conceptual understanding of the processes occurring at hydrocarbon-contaminated sites. For example, the DAF model in the HRC shows the following:

- Groundwater that emanates from the upgradient portions of the source zone follows a longer flow path and takes a longer period of time to reach the mixing zone; therefore, this groundwater will experience more biodegradation.
- The higher equivalent-carbon PAHs and aliphatics have very high k_{oc} values (indicating they sorb strongly to the soil), which result in very high retardation factors and very long travel times; therefore, even with long half-life values, the higher equivalent-carbon PAHs and aliphatics are characterized by high attenuation and low dissolved-phase transport.

B4 DAF Sensitivity Analysis

A sensitivity analysis was performed to show how varying the input parameters of the FMD DAF equation changed the calculated DAF values. In the sensitivity analysis, the saturated source thickness, half-life, and another parameter were changed while the remaining input parameters were held constant. The DAF input parameters and calculated DAF values are shown in Tables 1 through 7. Colored highlights show the set of input values that were varied from the assumed default condition. The effect of changes in the saturated zone source thickness, source length, infiltration rate, hydraulic conductivity, gradient, k_{oc} , f_{oc} , and biodegradation half-life are shown in Graphs 1 through 7. Recall that the groundwater entering the fixed-depth mixing zone may have come directly from (1) the NAPL-contaminated soil source zone without any attenuation; (2) the water that flowed from the bottom of the source zone, and is subject to biodegradation as it travels to the fixed mixing zone; or (3) water that did not contact the source and is interpreted to be uncontaminated. The proportion of the water in the mixing zone from each of these three pathways controls or defines the dilution factor. Biodegradation in the water flowing from the bottom of the source area before reaching the mixing zone controls the attenuation factor. The proportion of the water in the mixing zone from each of these three pathways is controlled by the location of the source relative to the high- and low-water table, the source length, infiltration rate, hydraulic conductivity, gradient, and aquifer thickness. The amount of biodegradation occurring in the water emanating from the bottom of the source zone is controlled by the half-life, f_{oc} , k_{oc} of the compound, source length, infiltration rate, hydraulic conductivity, and gradient. Many variables in the DAF used in the hydrocarbon risk calculator are inter-related or change as functions of each other. The values used as input to the sensitivity analysis are interpreted to be representative of conditions found at typical hydrocarbon-contaminated sites.

Tables 1 and Graphs 1A, 1B, and 1C show how the DAF changes as the source length, half-life, and saturated source thicknesses change. As the source length increases, the quantity of water emanating from the bottom of the source increases and the depth of contaminant at the downgradient edge of the source increases. Graph 1A has a relatively short half-life (25 days; typical of the toluene, ethylbenzene, and xylene [TEX] compounds), Graph 1B has a medium half-life (400 days; potentially representative of benzene); and Graph 1C has a very long half-life (100,000 days; resulting in biodegradation that is essentially zero, so that dilution is the only DAF process). Graph 1A shows the following:

- When biodegradation rates are high, most of the contaminant mass in the water emanating from the bottom of the source is biodegraded so that the DAF does not change with increasing source length, but rather becomes a function of the saturated (or submerged) source thickness
- Sources that have higher saturated (or submerged) thicknesses have lower DAFs.

Graph 1B shows the following:

- As the biodegradation rate decreases, the length of the source begins to have an impact on the DAF, with the shorter sources having a higher DAF.
- Given a half-life of 400 days, a low f_{oc} and low k_{oc} (which yields a retardation factor of only 1.5), biodegradation is still sufficient to minimize the effect of source length on the

DAF, so that the DAF becomes a function of the saturated (or submerged) source thickness.

Graph 1C shows the following:

- As the half-life increases and biodegradation becomes insignificant, the length of the source begins to have an impact on the DAF, with the shorter sources having a higher DAF and all values converging on a DAF of 1 as the source length increases.

Table 2 and Graphs 2A, 2B and 2C show the effect of changes in the infiltration rate on the DAF for several saturated source zone thicknesses. Increased infiltration rates cause increased amounts of water to emanate from the bottom of the source zone so that, at high infiltration rates, all water within the mixing zone depth has contacted the source zone. Graph 2A has a relatively short half-life (25 days; typical of the TEX compounds); Graph 2B has a medium half-life (400 days; potentially representative of benzene); and Graph 2C has a very long half-life (100,000 days; resulting in biodegradation that is essentially zero, so that dilution is the only DAF process). Graph 2A shows the following:

- When biodegradation rates are high, most of the contaminant mass in the water emanating from the bottom of the source is biodegraded, so that the DAF does not change with increasing infiltration, but rather becomes a function of the saturated (or submerged) source thickness
- Sources that have higher saturated (or submerged) thicknesses have lower DAFs.

Graph 2B shows the following:

- As the biodegradation rate decreases, the infiltration rates has an impact on the DAF, with the lower infiltration rates having a higher DAF.
- Given a half-life of 400 days, a low f_{oc} and low k_{oc} (which yields a retardation factor of only 1.5), biodegradation is still sufficient to minimize the effect of infiltration on the DAF, so that the DAF is still a function of the saturated (or submerged) source thickness.

Graph 2C shows the following:

- As the half-life increases and biodegradation becomes insignificant, the infiltration rate has a significant impact on the DAF, with the lower infiltration rates having a higher DAF and all values converging on a DAF of 1 as the infiltration rate increases.

Table 3 and Graphs 3A, 3B, and 3C show the effect of changes in the hydraulic conductivity on the DAF for several saturated source zone thicknesses. Increased hydraulic conductivities allow a given thickness of the aquifer to accommodate higher flow rates, so that as the hydraulic conductivity increases the water emanating from the bottom of the source is conducted in thinner layer, which tends to increase the dilution factor. Higher hydraulic conductivities also increase the groundwater velocities, which tends to reduce the impact of biodegradation, yielding lower attenuation rates. Graph 3A has a relatively short half-life (25 days; typical of the TEX compounds); Graph 3B has a medium half-life (400 days; potentially representative of benzene); and Graph 3C has a very long half-life (100,000 days; resulting in biodegradation that is essentially zero, so that dilution is the only DAF process). Graph 3A shows the following:

- When biodegradation rates are high, most of the contaminant mass in the water emanating from the bottom of the source is biodegraded, so that the DAF does not change with increasing hydraulic conductivity, but rather becomes a function of the saturated (or submerged) source thickness.
- Sources that have higher saturated (or submerged) thicknesses have lower DAFs.

Graph 3B shows the following:

- As the biodegradation rate decreases, the hydraulic conductivity has an impact on the DAF, with the higher hydraulic conductivities sites having a higher DAF.
- Given a half-life of 400 days, a low f_{oc} and low k_{oc} (which yields a retardation factor of only 1.5), biodegradation is still sufficient to minimize the effect of hydraulic conductivity on the DAF, so that the DAF becomes a function of the saturated (or submerged) source thickness.

Graph 3C shows the following:

- As the half-life increases and biodegradation becomes insignificant, the hydraulic conductivity has a significant impact on the DAF, with the lower hydraulic conductivity sites having a DAF of 1 and higher hydraulic conductivity sites having increasing DAFs, up to a limit based on the proportion of water flowing from the source directly into the mixing zone.

Table 4 and Graphs 4A, 4B, and 4C show the effect of changes in the hydraulic gradient on the DAF for several saturated source zone thicknesses. Increased hydraulic gradients allow a given thickness of the aquifer to accommodate higher flow rates, so that as the gradient increases the water emanating from the bottom of the source is conducted in thinner layer, which tends to increase the dilution factor. Higher gradients also increase the groundwater velocities, which tends to reduce the impact of biodegradation, yielding lower attenuation rates. Graph 4A has a relatively short half-life (25 days; typical of the TEX compounds); Graph 4B has a medium half-life (400 days; potentially representative of benzene); and Graph 4C has a very long half-life (100,000 days; resulting in biodegradation that is essentially zero, so that dilution is the only DAF process). Graph 4A shows the following:

- When biodegradation rates are high, most of the contaminant mass in the water emanating from the bottom of the source is biodegraded, so that the DAF does not change with increasing hydraulic gradient, but rather becomes a function of the saturated (or submerged) source thickness.
- Sources which have higher saturated (or submerged) thicknesses have lower DAFs.

Graph 4B shows the following:

- Given a half-life of 400 days, a low f_{oc} and low k_{oc} (which yields a retardation factor of only 1.5), biodegradation is still sufficient to minimize the effect of hydraulic gradient on the DAF, so that the DAF becomes a function of the saturated (or submerged) source thickness.

Graph 4C shows the following:

- As the half-life increases and biodegradation becomes insignificant, the gradient has a significant impact on the DAF, with the lower gradient sites having a DAF of 1 and higher gradient sites having increasing DAFs, up to a limit based on the proportion of water flowing from the source directly into the mixing zone.

Table 5 and Graph 5 show the effect of the organic carbon partitioning value (k_{oc} values) on the DAF. The k_{oc} is a property of each compound or fraction that describes how the compound sorbs to organics in the soil. The k_{oc} , f_{oc} , and bulk density are used to calculate a “retardation factor” for each compound or fraction. The retardation factor is a measure of how fast a compound or fraction is transported relative to the advective velocity of the groundwater. (A retardation factor of 10 means that the compound is transported at a tenth of the groundwater advective velocity.) Graph 5, which is calculated assuming a biodegradation half-life of 400 days, shows that as k_{oc} values increase, retardation increases to the point that most of the contaminant mass emanating from the bottom of the source has time to biodegrade during transport to the mixing zone, so that the DAF becomes a function of the saturated source thickness.

Table 6 and Graph 6 show how the f_{oc} in the soil affects the DAF. As described above, as the f_{oc} increases, the retardation factor increases, allowing more biodegradation to occur in a given transport distance. Graph 6, which is calculated assuming a biodegradation half-life of 400 days, shows that as f_{oc} values increase, retardation increases to the point that most of the contaminant mass emanating from the bottom of the source has time to biodegrade during transport to the mixing zone, so that the DAF becomes a function of the saturated source thickness.

Table 7 and Graph 7 show the effect of the half-life value on the DAF given the ADEC default site conditions and several saturated source thicknesses. Graph 7 shows that for compounds with low half-life values (i.e., high biodegradation rates), vadose zone sources would be expected to yield very high DAF values, and that when the source extends into the saturated zone, the saturated source thickness has a limiting effect on the DAF. In the example calculations, when sources are in the smear zone, the DAF increases as the half-life decreases, but the saturated source zone thickness controls the overall DAF value.

B5 References

Alaska Department of Environmental Conservation (ADEC). 2008. “Oil Spill and Hazardous Substances Pollution Control Regulations.” *Alaska Administrative Code*. Title 18, Chapter 75.

Buscheck, T. E., and C. M. Alcantar. 1995. “Regression Techniques and Analytical Solutions to Demonstrate Intrinsic Bioremediation.” In *Proceedings of the 1995 Battelle International Conference on In-situ and On Site Bioreclamation*, Hinchee and Olfenbuttel eds., Battelle Memorial Institute, Butterworth-Heinemann, Boston, MA.

Table 1 Migration-to-Groundwater Source Length Sensitivity Analysis

Saturated Source Thickness (ft)	Source Length (ft)	Aquifer Thickness (ft)	Hydraulic Conductivity (m/yr)	Hydraulic Gradient (m/yr)	Infiltration Rate (m/yr)	Half Life (days)	Koc	foc	Retardation Factor	Representative Compounds	Dilution Factor	Attenuation Factor	Dilution-Attenuation Factor
0	10.00	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.4E+01	1.3E+01	3.1E+02
0	50.00	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	4.9E+00	2.0E+02	9.8E+02
0	105	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+00	5.5E+03	1.3E+04
0	200	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.2E+00	1.7E+06	2.0E+06
0	500	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.2E+07	2.2E+07
1	10.00	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.1E+01	1.6E+00	1.8E+01
1	50.00	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	4.0E+00	4.6E+00	1.9E+01
1	105	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.2E+00	8.8E+00	1.9E+01
1	200	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.2E+00	1.6E+01	1.9E+01
1	500	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.9E+01	1.9E+01
3	10.00	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	5.6E+00	1.2E+00	6.9E+00
3	50.00	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	3.1E+00	2.2E+00	7.0E+00
3	105	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	3.6E+00	7.0E+00
3	200	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.2E+00	5.9E+00	7.0E+00
3	500	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	7.0E+00	7.0E+00
6	10.00	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	3.6E+00	1.1E+00	4.0E+00
6	50.00	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.5E+00	1.6E+00	4.0E+00
6	105	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.7E+00	2.3E+00	4.0E+00
6	200	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.2E+00	3.5E+00	4.0E+00
6	500	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	4.0E+00	4.0E+00
10	10.00	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.6E+00	1.1E+00	2.8E+00
10	50.00	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	1.4E+00	2.8E+00
10	105	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.6E+00	1.8E+00	2.8E+00
10	200	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.1E+00	2.5E+00	2.8E+00
10	500	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.8E+00	2.8E+00
0	10.00	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.4E+01	1.4E+00	3.5E+01
0	50.00	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	4.9E+00	3.9E+00	1.9E+01
0	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+00	8.1E+00	1.9E+01
0	200	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.2E+00	1.6E+01	2.0E+01
0	500	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.1E+01	2.1E+01
1	10.00	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.1E+01	1.1E+00	1.3E+01
1	50.00	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	4.0E+00	2.4E+00	9.7E+00
1	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.2E+00	4.5E+00	9.7E+00
1	200	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.2E+00	8.3E+00	1.0E+01
1	500	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+01	1.0E+01
3	10.00	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	5.6E+00	1.1E+00	6.0E+00
3	50.00	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	3.1E+00	1.7E+00	5.3E+00
3	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	2.7E+00	5.3E+00
3	200	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.2E+00	4.6E+00	5.4E+00
3	500	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	5.4E+00	5.4E+00

Table 1 Migration-to-Groundwater Source Length Sensitivity Analysis

Saturated Source Thickness (ft)	Source Length (ft)	Aquifer Thickness (ft)	Hydraulic Conductivity (m/yr)	Hydraulic Gradient (m/yr)	Infiltration Rate (m/yr)	Half Life (days)	Koc	foc	Retardation Factor	Representative Compounds	Dilution Factor	Attenuation Factor	Dilution-Attenuation Factor
6	10.00	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	3.6E+00	1.0E+00	3.7E+00
6	50.00	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.5E+00	1.4E+00	3.5E+00
6	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.7E+00	2.0E+00	3.5E+00
6	200	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.2E+00	3.0E+00	3.5E+00
6	500	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	3.5E+00	3.5E+00
10	10.00	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.6E+00	1.0E+00	2.7E+00
10	50.00	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	1.3E+00	2.6E+00
10	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.6E+00	1.6E+00	2.6E+00
10	200	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.1E+00	2.3E+00	2.6E+00
10	500	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.6E+00	2.6E+00
0	10.00	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.4E+01	1.0E+00	2.4E+01
0	50.00	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	4.9E+00	1.0E+00	4.9E+00
0	105	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+00	1.0E+00	2.4E+00
0	200	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.2E+00	1.0E+00	1.3E+00
0	500	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
1	10.00	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.1E+01	1.0E+00	1.1E+01
1	50.00	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	4.0E+00	1.0E+00	4.1E+00
1	105	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.2E+00	1.0E+00	2.2E+00
1	200	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.2E+00	1.0E+00	1.2E+00
1	500	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
3	10.00	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	5.6E+00	1.0E+00	5.6E+00
3	50.00	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	3.1E+00	1.0E+00	3.1E+00
3	105	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	1.0E+00	2.0E+00
3	200	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.2E+00	1.0E+00	1.2E+00
3	500	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
6	10.00	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	3.6E+00	1.0E+00	3.6E+00
6	50.00	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.5E+00	1.0E+00	2.5E+00
6	105	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.7E+00	1.0E+00	1.8E+00
6	200	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.2E+00	1.0E+00	1.2E+00
6	500	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
10	10.00	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.6E+00	1.0E+00	2.6E+00
10	50.00	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	1.0E+00	2.0E+00
10	105	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.6E+00	1.0E+00	1.6E+00
10	200	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.1E+00	1.0E+00	1.1E+00
10	500	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00

Table 2 Migration-to-Groundwater Infiltration Rate Sensitivity Analysis

Saturated Source Thickness (ft)	Source Length (ft)	Aquifer Thickness (ft)	Hydraulic Conductivity (m/yr)	Hydraulic Gradient (m/yr)	Infiltration Rate (m/yr)	Half Life (days)	Koc	foc	Retardation Factor	Representative Compounds	Dilution Factor	Attenuation Factor	Dilution-Attenuation Factor
0	105	32	876	0.002	0.0065	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	4.6E+01	5.5E+03	2.5E+05
0	105	32	876	0.002	0.013	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+01	5.5E+03	1.3E+05
0	105	32	876	0.002	0.065	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	4.6E+00	5.5E+03	2.5E+04
0	105	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+00	5.5E+03	1.3E+04
0	105	32	876	0.002	0.6	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.4E+02	2.4E+02
1	105	32	876	0.002	0.0065	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.4E+01	1.4E+00	1.9E+01
1	105	32	876	0.002	0.013	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.1E+01	1.8E+00	1.9E+01
1	105	32	876	0.002	0.065	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	3.9E+00	4.9E+00	1.9E+01
1	105	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.2E+00	8.8E+00	1.9E+01
1	105	32	876	0.002	0.6	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.8E+01	1.8E+01
3	105	32	876	0.002	0.0065	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	6.2E+00	1.1E+00	7.0E+00
3	105	32	876	0.002	0.013	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	5.6E+00	1.3E+00	7.0E+00
3	105	32	876	0.002	0.065	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	3.1E+00	2.3E+00	7.0E+00
3	105	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	3.6E+00	7.0E+00
3	105	32	876	0.002	0.6	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	6.8E+00	6.8E+00
6	105	32	876	0.002	0.0065	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	3.8E+00	1.1E+00	4.0E+00
6	105	32	876	0.002	0.013	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	3.5E+00	1.1E+00	4.0E+00
6	105	32	876	0.002	0.065	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.4E+00	1.6E+00	4.0E+00
6	105	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.7E+00	2.3E+00	4.0E+00
6	105	32	876	0.002	0.6	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	4.0E+00	4.0E+00
10	105	32	876	0.002	0.0065	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.7E+00	1.0E+00	2.8E+00
10	105	32	876	0.002	0.013	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.6E+00	1.1E+00	2.8E+00
10	105	32	876	0.002	0.065	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	1.4E+00	2.8E+00
10	105	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.6E+00	1.8E+00	2.8E+00
10	105	32	876	0.002	0.6	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.8E+00	2.8E+00
0	105	32	876	0.002	0.0065	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	4.6E+01	8.1E+00	3.7E+02
0	105	32	876	0.002	0.013	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+01	8.1E+00	1.9E+02
0	105	32	876	0.002	0.065	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	4.6E+00	8.1E+00	3.7E+01
0	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+00	8.1E+00	1.9E+01
0	105	32	876	0.002	0.6	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	4.1E+00	4.1E+00
1	105	32	876	0.002	0.0065	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.4E+01	1.3E+00	1.8E+01
1	105	32	876	0.002	0.013	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.1E+01	1.6E+00	1.7E+01
1	105	32	876	0.002	0.065	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	3.9E+00	3.3E+00	1.3E+01
1	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.2E+00	4.5E+00	9.7E+00
1	105	32	876	0.002	0.6	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	3.5E+00	3.5E+00
3	105	32	876	0.002	0.0065	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	6.2E+00	1.1E+00	6.9E+00
3	105	32	876	0.002	0.013	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	5.6E+00	1.2E+00	6.8E+00
3	105	32	876	0.002	0.065	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	3.1E+00	2.0E+00	6.0E+00
3	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	2.7E+00	5.3E+00
3	105	32	876	0.002	0.6	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.8E+00	2.8E+00

Table 2 Migration-to-Groundwater Infiltration Rate Sensitivity Analysis

Saturated Source Thickness (ft)	Source Length (ft)	Aquifer Thickness (ft)	Hydraulic Conductivity (m/yr)	Hydraulic Gradient (m/yr)	Infiltration Rate (m/yr)	Half Life (days)	Koc	foc	Retardation Factor	Representative Compounds	Dilution Factor	Attenuation Factor	Dilution-Attenuation Factor
6	105	32	876	0.002	0.0065	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	3.8E+00	1.1E+00	4.0E+00
6	105	32	876	0.002	0.013	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	3.5E+00	1.1E+00	3.9E+00
6	105	32	876	0.002	0.065	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.4E+00	1.5E+00	3.7E+00
6	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.7E+00	2.0E+00	3.5E+00
6	105	32	876	0.002	0.6	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.3E+00	2.3E+00
10	105	32	876	0.002	0.0065	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.7E+00	1.0E+00	2.8E+00
10	105	32	876	0.002	0.013	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.6E+00	1.1E+00	2.8E+00
10	105	32	876	0.002	0.065	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	1.3E+00	2.7E+00
10	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.6E+00	1.6E+00	2.6E+00
10	105	32	876	0.002	0.6	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.9E+00	1.9E+00
0	105	32	876	0.002	0.0065	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	4.6E+01	1.0E+00	4.7E+01
0	105	32	876	0.002	0.013	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+01	1.0E+00	2.4E+01
0	105	32	876	0.002	0.065	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	4.6E+00	1.0E+00	4.7E+00
0	105	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+00	1.0E+00	2.4E+00
0	105	32	876	0.002	0.6	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
1	105	32	876	0.002	0.0065	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.4E+01	1.0E+00	1.4E+01
1	105	32	876	0.002	0.013	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.1E+01	1.0E+00	1.1E+01
1	105	32	876	0.002	0.065	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	3.9E+00	1.0E+00	3.9E+00
1	105	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.2E+00	1.0E+00	2.2E+00
1	105	32	876	0.002	0.6	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
3	105	32	876	0.002	0.0065	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	6.2E+00	1.0E+00	6.2E+00
3	105	32	876	0.002	0.013	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	5.6E+00	1.0E+00	5.6E+00
3	105	32	876	0.002	0.065	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	3.1E+00	1.0E+00	3.1E+00
3	105	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	1.0E+00	2.0E+00
3	105	32	876	0.002	0.6	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
6	105	32	876	0.002	0.0065	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	3.8E+00	1.0E+00	3.8E+00
6	105	32	876	0.002	0.013	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	3.5E+00	1.0E+00	3.6E+00
6	105	32	876	0.002	0.065	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.4E+00	1.0E+00	2.4E+00
6	105	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.7E+00	1.0E+00	1.8E+00
6	105	32	876	0.002	0.6	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
10	105	32	876	0.002	0.0065	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.7E+00	1.0E+00	2.7E+00
10	105	32	876	0.002	0.013	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.6E+00	1.0E+00	2.6E+00
10	105	32	876	0.002	0.065	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	1.0E+00	2.0E+00
10	105	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.6E+00	1.0E+00	1.6E+00
10	105	32	876	0.002	0.6	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00

Table 3 Migration-to-Groundwater Hydraulic Conductivity Sensitivity Analysis

Saturated Source Thickness (ft)	Source Length (ft)	Aquifer Thickness (ft)	Hydraulic Conductivity (m/yr)	Hydraulic Gradient (m/yr)	Infiltration Rate (m/yr)	Half Life (days)	Koc	foc	Retardation Factor	Representative Compounds	Dilution Factor	Attenuation Factor	Dilution-Attenuation Factor
0	105	32	87600	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+02	1.8E+00	4.1E+02
0	105	32	8760	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+01	1.3E+01	3.1E+02
0	105	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+00	5.5E+03	1.3E+04
0	105	32	87.6	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.2E+07	2.2E+07
0	105	32	8.76	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.2E+07	2.2E+07
0	105	32	0.876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.2E+07	2.2E+07
1	105	32	87600	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.8E+01	1.0E+00	1.8E+01
1	105	32	8760	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.1E+01	1.7E+00	1.8E+01
1	105	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.2E+00	8.8E+00	1.9E+01
1	105	32	87.6	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.9E+01	1.9E+01
1	105	32	8.76	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.9E+01	1.9E+01
1	105	32	0.876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.9E+01	1.9E+01
3	105	32	87600	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	6.8E+00	1.0E+00	6.9E+00
3	105	32	8760	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	5.6E+00	1.2E+00	6.9E+00
3	105	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	3.6E+00	7.0E+00
3	105	32	87.6	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	7.0E+00	7.0E+00
3	105	32	8.76	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	7.0E+00	7.0E+00
3	105	32	0.876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	7.0E+00	7.0E+00
6	105	32	87600	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	4.0E+00	1.0E+00	4.0E+00
6	105	32	8760	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	3.5E+00	1.1E+00	4.0E+00
6	105	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.7E+00	2.3E+00	4.0E+00
6	105	32	87.6	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	4.0E+00	4.0E+00
6	105	32	8.76	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	4.0E+00	4.0E+00
6	105	32	0.876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	4.0E+00	4.0E+00
10	105	32	87600	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.8E+00	1.0E+00	2.8E+00
10	105	32	8760	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.6E+00	1.1E+00	2.8E+00
10	105	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.6E+00	1.8E+00	2.8E+00
10	105	32	87.6	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.8E+00	2.8E+00
10	105	32	8.76	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.8E+00	2.8E+00
10	105	32	0.876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.8E+00	2.8E+00
0	105	32	87600	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+02	1.0E+00	2.4E+02
0	105	32	8760	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+01	1.4E+00	3.3E+01
0	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+00	8.1E+00	1.9E+01
0	105	32	87.6	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.1E+01	2.1E+01
0	105	32	8.76	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.1E+01	2.1E+01
0	105	32	0.876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.1E+01	2.1E+01
1	105	32	87600	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.8E+01	1.0E+00	1.8E+01
1	105	32	8760	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.1E+01	1.2E+00	1.2E+01
1	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.2E+00	4.5E+00	9.7E+00
1	105	32	87.6	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+01	1.0E+01
1	105	32	8.76	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+01	1.0E+01
1	105	32	0.876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+01	1.0E+01
3	105	32	87600	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	6.8E+00	1.0E+00	6.8E+00
3	105	32	8760	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	5.6E+00	1.1E+00	5.9E+00
3	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	2.7E+00	5.3E+00
3	105	32	87.6	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	5.4E+00	5.4E+00
3	105	32	8.76	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	5.4E+00	5.4E+00
3	105	32	0.876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	5.4E+00	5.4E+00

Table 3 Migration-to-Groundwater Hydraulic Conductivity Sensitivity Analysis

Saturated Source Thickness (ft)	Source Length (ft)	Aquifer Thickness (ft)	Hydraulic Conductivity (m/yr)	Hydraulic Gradient (m/yr)	Infiltration Rate (m/yr)	Half Life (days)	Koc	foc	Retardation Factor	Representative Compounds	Dilution Factor	Attenuation Factor	Dilution-Attenuation Factor
6	105	32	87600	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	4.0E+00	1.0E+00	4.0E+00
6	105	32	8760	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	3.5E+00	1.0E+00	3.7E+00
6	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.7E+00	2.0E+00	3.5E+00
6	105	32	87.6	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	3.5E+00	3.5E+00
6	105	32	8.76	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	3.5E+00	3.5E+00
6	105	32	0.876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	3.5E+00	3.5E+00
10	105	32	87600	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.8E+00	1.0E+00	2.8E+00
10	105	32	8760	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.6E+00	1.0E+00	2.7E+00
10	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.6E+00	1.6E+00	2.6E+00
10	105	32	87.6	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.6E+00	2.6E+00
10	105	32	8.76	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.6E+00	2.6E+00
10	105	32	0.876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.6E+00	2.6E+00
0	105	32	87600	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+02	1.0E+00	2.3E+02
0	105	32	8760	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+01	1.0E+00	2.3E+01
0	105	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+00	1.0E+00	2.4E+00
0	105	32	87.6	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
0	105	32	8.76	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
0	105	32	0.876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
1	105	32	87600	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.8E+01	1.0E+00	1.8E+01
1	105	32	8760	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.1E+01	1.0E+00	1.1E+01
1	105	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.2E+00	1.0E+00	2.2E+00
1	105	32	87.6	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
1	105	32	8.76	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
1	105	32	0.876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
3	105	32	87600	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	6.8E+00	1.0E+00	6.8E+00
3	105	32	8760	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	5.6E+00	1.0E+00	5.6E+00
3	105	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	1.0E+00	2.0E+00
3	105	32	87.6	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
3	105	32	8.76	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
3	105	32	0.876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
6	105	32	87600	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	4.0E+00	1.0E+00	4.0E+00
6	105	32	8760	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	3.5E+00	1.0E+00	3.5E+00
6	105	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.7E+00	1.0E+00	1.8E+00
6	105	32	87.6	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
6	105	32	8.76	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
6	105	32	0.876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
10	105	32	87600	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.8E+00	1.0E+00	2.8E+00
10	105	32	8760	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.6E+00	1.0E+00	2.6E+00
10	105	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.6E+00	1.0E+00	1.6E+00
10	105	32	87.6	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
10	105	32	8.76	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
10	105	32	0.876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00

Table 4 Migration-to-Groundwater Gradient Sensitivity Analysis

Saturated Source Thickness (ft)	Source Length (ft)	Aquifer Thickness (ft)	Hydraulic Conductivity (m/yr)	Hydraulic Gradient (m/yr)	Infiltration Rate (m/yr)	Half Life (days)	Koc	foc	Retardation Factor	Representative Compounds	Dilution Factor	Attenuation Factor	Dilution-Attenuation Factor
0	105	32	876	0.0001	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.2E+07	2.2E+07
0	105	32	876	0.0005	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.2E+07	2.2E+07
0	105	32	876	0.001	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.2E+00	3.0E+06	3.5E+06
0	105	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+00	5.5E+03	1.3E+04
0	105	32	876	0.005	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	5.8E+00	1.2E+02	7.2E+02
0	105	32	876	0.01	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.2E+01	3.2E+01	3.8E+02
1	105	32	876	0.0001	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.9E+01	1.9E+01
1	105	32	876	0.0005	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.9E+01	1.9E+01
1	105	32	876	0.001	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.1E+00	1.7E+01	1.9E+01
1	105	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.2E+00	8.8E+00	1.9E+01
1	105	32	876	0.005	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	4.6E+00	4.0E+00	1.9E+01
1	105	32	876	0.01	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	7.4E+00	2.4E+00	1.8E+01
3	105	32	876	0.0001	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	7.0E+00	7.0E+00
3	105	32	876	0.0005	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	7.0E+00	7.0E+00
3	105	32	876	0.001	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.1E+00	6.2E+00	7.0E+00
3	105	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	3.6E+00	7.0E+00
3	105	32	876	0.005	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	3.4E+00	2.0E+00	7.0E+00
3	105	32	876	0.01	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	4.6E+00	1.5E+00	6.9E+00
6	105	32	876	0.0001	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	4.0E+00	4.0E+00
6	105	32	876	0.0005	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	4.0E+00	4.0E+00
6	105	32	876	0.001	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.1E+00	3.6E+00	4.0E+00
6	105	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.7E+00	2.3E+00	4.0E+00
6	105	32	876	0.005	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.6E+00	1.5E+00	4.0E+00
6	105	32	876	0.01	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	3.2E+00	1.2E+00	4.0E+00
10	105	32	876	0.0001	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.8E+00	2.8E+00
10	105	32	876	0.0005	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.8E+00	2.8E+00
10	105	32	876	0.001	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.1E+00	2.6E+00	2.8E+00
10	105	32	876	0.002	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.6E+00	1.8E+00	2.8E+00
10	105	32	876	0.005	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.1E+00	1.3E+00	2.8E+00
10	105	32	876	0.01	0.13	25	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.4E+00	1.2E+00	2.8E+00
0	105	32	876	0.0001	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.1E+01	2.1E+01
0	105	32	876	0.0005	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.1E+01	2.1E+01
0	105	32	876	0.001	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.1E+01	2.1E+01
0	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+00	8.1E+00	1.9E+01
0	105	32	876	0.005	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	5.8E+00	3.3E+00	1.9E+01
0	105	32	876	0.01	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.2E+01	2.0E+00	2.3E+01
1	105	32	876	0.0001	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+01	1.0E+01
1	105	32	876	0.0005	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+01	1.0E+01
1	105	32	876	0.001	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.1E+00	8.8E+00	1.0E+01
1	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.2E+00	4.5E+00	9.7E+00
1	105	32	876	0.005	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	4.6E+00	2.1E+00	9.8E+00
1	105	32	876	0.01	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	7.4E+00	1.4E+00	1.1E+01
3	105	32	876	0.0001	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	5.4E+00	5.4E+00
3	105	32	876	0.0005	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	5.4E+00	5.4E+00
3	105	32	876	0.001	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.1E+00	4.8E+00	5.4E+00
3	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	2.7E+00	5.3E+00
3	105	32	876	0.005	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	3.4E+00	1.6E+00	5.3E+00
3	105	32	876	0.01	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	4.6E+00	1.2E+00	5.6E+00

Table 4 Migration-to-Groundwater Gradient Sensitivity Analysis

Saturated Source Thickness (ft)	Source Length (ft)	Aquifer Thickness (ft)	Hydraulic Conductivity (m/yr)	Hydraulic Gradient (m/yr)	Infiltration Rate (m/yr)	Half Life (days)	Koc	foc	Retardation Factor	Representative Compounds	Dilution Factor	Attenuation Factor	Dilution-Attenuation Factor
6	105	32	876	0.0001	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	3.5E+00	3.5E+00
6	105	32	876	0.0005	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	3.5E+00	3.5E+00
6	105	32	876	0.001	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	3.5E+00	3.5E+00
6	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.7E+00	2.0E+00	3.5E+00
6	105	32	876	0.005	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.6E+00	1.3E+00	3.5E+00
6	105	32	876	0.01	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	3.2E+00	1.1E+00	3.5E+00
10	105	32	876	0.0001	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.6E+00	2.6E+00
10	105	32	876	0.0005	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	2.6E+00	2.6E+00
10	105	32	876	0.001	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.1E+00	2.3E+00	2.6E+00
10	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.6E+00	1.6E+00	2.6E+00
10	105	32	876	0.005	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.1E+00	1.2E+00	2.6E+00
10	105	32	876	0.01	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.4E+00	1.1E+00	2.6E+00
0	105	32	876	0.0001	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
0	105	32	876	0.0005	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
0	105	32	876	0.001	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.2E+00	1.0E+00	1.2E+00
0	105	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+00	1.0E+00	2.4E+00
0	105	32	876	0.005	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	5.8E+00	1.0E+00	5.8E+00
0	105	32	876	0.01	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.2E+01	1.0E+00	1.2E+01
1	105	32	876	0.0001	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
1	105	32	876	0.0005	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
1	105	32	876	0.001	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.1E+00	1.0E+00	1.2E+00
1	105	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.2E+00	1.0E+00	2.2E+00
1	105	32	876	0.005	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	4.6E+00	1.0E+00	4.6E+00
1	105	32	876	0.01	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	7.4E+00	1.0E+00	7.5E+00
3	105	32	876	0.0001	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
3	105	32	876	0.0005	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
3	105	32	876	0.001	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.1E+00	1.0E+00	1.2E+00
3	105	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	1.0E+00	2.0E+00
3	105	32	876	0.005	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	3.4E+00	1.0E+00	3.5E+00
3	105	32	876	0.01	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	4.6E+00	1.0E+00	4.6E+00
6	105	32	876	0.0001	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
6	105	32	876	0.0005	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
6	105	32	876	0.001	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.1E+00	1.0E+00	1.1E+00
6	105	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.7E+00	1.0E+00	1.8E+00
6	105	32	876	0.005	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.6E+00	1.0E+00	2.6E+00
6	105	32	876	0.01	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	3.2E+00	1.0E+00	3.2E+00
10	105	32	876	0.0001	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
10	105	32	876	0.0005	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.0E+00	1.0E+00	1.0E+00
10	105	32	876	0.001	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.1E+00	1.0E+00	1.1E+00
10	105	32	876	0.002	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.6E+00	1.0E+00	1.6E+00
10	105	32	876	0.005	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.1E+00	1.0E+00	2.1E+00
10	105	32	876	0.01	0.13	100,000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.4E+00	1.0E+00	2.4E+00

Table 5 Migration-to-Groundwater Koc Sensitivity Analysis

Saturated Source Thickness (ft)	Source Length (ft)	Aquifer Thickness (ft)	Hydraulic Conductivity (m/yr)	Hydraulic Gradient (m/yr)	Infiltration Rate (m/yr)	Half Life (days)	Koc	foc	Retardation Factor	Representative Compounds	Dilution Factor	Attenuation Factor	Dilution-Attenuation Factor
0	105	32	876	0.002	0.13	1000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+00	3.3E+00	7.7E+00
0	105	32	876	0.002	0.13	1000	1.8E+03	0.001	7.35	Naphthalene (TMB, GRO aro, DRO aro similar)	2.3E+00	1.6E+01	3.7E+01
0	105	32	876	0.002	0.13	1000	2.1E+04	0.001	72.90	Phenanthrene (Benzo (g,h,i) perylene similar)	2.3E+00	1.5E+04	3.5E+04
0	105	32	876	0.002	0.13	1000	2.3E+05	0.001	799.5	Benzo (a) Anthracene (DRO aliphatics similar)	2.3E+00	6.6E+35	1.5E+36
0	105	32	876	0.002	0.13	1000	7.9E+05	0.001	2721.3	Benzo (a) pyrene (Benzo (k) fluoranthene, Benzo (b) fluoranthene similar)	2.3E+00	3.3E+119	7.6E+119
0	105	32	876	0.002	0.13	1000	2.6E+06	0.001	9057.1	Dibenz (a,h) anthracene (Indeno (1,2,3-cd) pyrene, Benzo (g,h,i) perylene similar)	2.3E+00	infinite	infinite
0	105	32	876	0.002	0.13	1000	4.8E+11	0.001	1.65E+09	RRO Aliphatics	2.3E+00	infinite	infinite
1	105	32	876	0.002	0.13	1000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.2E+00	2.6E+00	5.7E+00
1	105	32	876	0.002	0.13	1000	1.8E+03	0.001	7.35	Naphthalene (TMB, GRO aro, DRO aro similar)	2.2E+00	5.9E+00	1.3E+01
1	105	32	876	0.002	0.13	1000	2.1E+04	0.001	72.90	Phenanthrene (Benzo (g,h,i) perylene similar)	2.2E+00	8.8E+00	1.9E+01
1	105	32	876	0.002	0.13	1000	2.3E+05	0.001	799.5	Benzo (a) Anthracene (DRO aliphatics similar)	2.2E+00	8.8E+00	1.9E+01
1	105	32	876	0.002	0.13	1000	7.9E+05	0.001	2721.3	Benzo (a) pyrene (Benzo (k) fluoranthene, Benzo (b) fluoranthene similar)	2.2E+00	8.8E+00	1.9E+01
1	105	32	876	0.002	0.13	1000	2.6E+06	0.001	9057.1	Dibenz (a,h) anthracene (Indeno (1,2,3-cd) pyrene, Benzo (g,h,i) perylene similar)	2.2E+00	8.8E+00	1.9E+01
1	105	32	876	0.002	0.13	1000	4.8E+11	0.001	1.65E+09	RRO Aliphatics	2.2E+00	8.8E+00	1.9E+01
3	105	32	876	0.002	0.13	1000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	2.0E+00	3.9E+00
3	105	32	876	0.002	0.13	1000	1.8E+03	0.001	7.35	Naphthalene (TMB, GRO aro, DRO aro similar)	2.0E+00	3.1E+00	6.0E+00
3	105	32	876	0.002	0.13	1000	2.1E+04	0.001	72.90	Phenanthrene (Benzo (g,h,i) perylene similar)	2.0E+00	3.6E+00	7.0E+00
3	105	32	876	0.002	0.13	1000	2.3E+05	0.001	799.5	Benzo (a) Anthracene (DRO aliphatics similar)	2.0E+00	3.6E+00	7.0E+00
3	105	32	876	0.002	0.13	1000	7.9E+05	0.001	2721.3	Benzo (a) pyrene (Benzo (k) fluoranthene, Benzo (b) fluoranthene similar)	2.0E+00	3.6E+00	7.0E+00
3	105	32	876	0.002	0.13	1000	2.6E+06	0.001	9057.1	Dibenz (a,h) anthracene (Indeno (1,2,3-cd) pyrene, Benzo (g,h,i) perylene similar)	2.0E+00	3.6E+00	7.0E+00
3	105	32	876	0.002	0.13	1000	4.8E+11	0.001	1.65E+09	RRO Aliphatics	2.0E+00	3.6E+00	7.0E+00
6	105	32	876	0.002	0.13	1000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.7E+00	1.7E+00	2.9E+00
6	105	32	876	0.002	0.13	1000	1.8E+03	0.001	7.35	Naphthalene (TMB, GRO aro, DRO aro similar)	1.7E+00	2.1E+00	3.7E+00
6	105	32	876	0.002	0.13	1000	2.1E+04	0.001	72.90	Phenanthrene (Benzo (g,h,i) perylene similar)	1.7E+00	2.3E+00	4.0E+00
6	105	32	876	0.002	0.13	1000	2.3E+05	0.001	799.5	Benzo (a) Anthracene (DRO aliphatics similar)	1.7E+00	2.3E+00	4.0E+00
6	105	32	876	0.002	0.13	1000	7.9E+05	0.001	2721.3	Benzo (a) pyrene (Benzo (k) fluoranthene, Benzo (b) fluoranthene similar)	1.7E+00	2.3E+00	4.0E+00
6	105	32	876	0.002	0.13	1000	2.6E+06	0.001	9057.1	Dibenz (a,h) anthracene (Indeno (1,2,3-cd) pyrene, Benzo (g,h,i) perylene similar)	1.7E+00	2.3E+00	4.0E+00
6	105	32	876	0.002	0.13	1000	4.8E+11	0.001	1.65E+09	RRO Aliphatics	1.7E+00	2.3E+00	4.0E+00
10	105	32	876	0.002	0.13	1000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.6E+00	1.4E+00	2.3E+00
10	105	32	876	0.002	0.13	1000	1.8E+03	0.001	7.35	Naphthalene (TMB, GRO aro, DRO aro similar)	1.6E+00	1.7E+00	2.7E+00
10	105	32	876	0.002	0.13	1000	2.1E+04	0.001	72.90	Phenanthrene (Benzo (g,h,i) perylene similar)	1.6E+00	1.8E+00	2.8E+00
10	105	32	876	0.002	0.13	1000	2.3E+05	0.001	799.5	Benzo (a) Anthracene (DRO aliphatics similar)	1.6E+00	1.8E+00	2.8E+00
10	105	32	876	0.002	0.13	1000	7.9E+05	0.001	2721.3	Benzo (a) pyrene (Benzo (k) fluoranthene, Benzo (b) fluoranthene similar)	1.6E+00	1.8E+00	2.8E+00
10	105	32	876	0.002	0.13	1000	2.6E+06	0.001	9057.1	Dibenz (a,h) anthracene (Indeno (1,2,3-cd) pyrene, Benzo (g,h,i) perylene similar)	1.6E+00	1.8E+00	2.8E+00
10	105	32	876	0.002	0.13	1000	4.8E+11	0.001	1.65E+09	RRO Aliphatics	1.6E+00	1.8E+00	2.8E+00

Table 6 Migration-to-Groundwater foc Sensitivity Analysis

Saturated Source Thickness (ft)	Source Length (ft)	Aquifer Thickness (ft)	Hydraulic Conductivity (m/yr)	Hydraulic Gradient (m/yr)	Infiltration Rate (m)	Half Life (days)	Koc	foc	Retardation Factor	Representative Compounds	Dilution Factor	Attenuation Factor	Dilution-Attenuation Factor
0	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+00	8.1E+00	1.9E+01
0	105	32	876	0.002	0.13	400	1.7E+02	0.005	3.860	Benzene (TEX similar)	2.3E+00	2.3E+01	5.2E+01
0	105	32	876	0.002	0.13	400	1.7E+02	0.010	6.721	Benzene (TEX similar)	2.3E+00	5.2E+01	1.2E+02
0	105	32	876	0.002	0.13	400	1.7E+02	0.020	12.441	Benzene (TEX similar)	2.3E+00	2.3E+02	5.2E+02
0	105	32	876	0.002	0.13	400	1.7E+02	0.050	29.603	Benzene (TEX similar)	2.3E+00	1.7E+04	3.9E+04
0	105	32	876	0.002	0.13	400	1.7E+02	0.100	58.205	Benzene (TEX similar)	2.3E+00	2.2E+07	5.0E+07
1	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.2E+00	4.5E+00	9.7E+00
1	105	32	876	0.002	0.13	400	1.7E+02	0.005	3.860	Benzene (TEX similar)	2.2E+00	6.5E+00	1.4E+01
1	105	32	876	0.002	0.13	400	1.7E+02	0.010	6.721	Benzene (TEX similar)	2.2E+00	7.6E+00	1.7E+01
1	105	32	876	0.002	0.13	400	1.7E+02	0.020	12.441	Benzene (TEX similar)	2.2E+00	8.5E+00	1.8E+01
1	105	32	876	0.002	0.13	400	1.7E+02	0.050	29.603	Benzene (TEX similar)	2.2E+00	8.8E+00	1.9E+01
1	105	32	876	0.002	0.13	400	1.7E+02	0.100	58.205	Benzene (TEX similar)	2.2E+00	8.8E+00	1.9E+01
3	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	2.7E+00	5.3E+00
3	105	32	876	0.002	0.13	400	1.7E+02	0.005	3.860	Benzene (TEX similar)	2.0E+00	3.2E+00	6.3E+00
3	105	32	876	0.002	0.13	400	1.7E+02	0.010	6.721	Benzene (TEX similar)	2.0E+00	3.4E+00	6.7E+00
3	105	32	876	0.002	0.13	400	1.7E+02	0.020	12.441	Benzene (TEX similar)	2.0E+00	3.6E+00	6.9E+00
3	105	32	876	0.002	0.13	400	1.7E+02	0.050	29.603	Benzene (TEX similar)	2.0E+00	3.6E+00	7.0E+00
3	105	32	876	0.002	0.13	400	1.7E+02	0.100	58.205	Benzene (TEX similar)	2.0E+00	3.6E+00	7.0E+00
6	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.7E+00	2.0E+00	3.5E+00
6	105	32	876	0.002	0.13	400	1.7E+02	0.005	3.860	Benzene (TEX similar)	1.7E+00	2.2E+00	3.8E+00
6	105	32	876	0.002	0.13	400	1.7E+02	0.010	6.721	Benzene (TEX similar)	1.7E+00	2.2E+00	3.9E+00
6	105	32	876	0.002	0.13	400	1.7E+02	0.020	12.441	Benzene (TEX similar)	1.7E+00	2.3E+00	4.0E+00
6	105	32	876	0.002	0.13	400	1.7E+02	0.050	29.603	Benzene (TEX similar)	1.7E+00	2.3E+00	4.0E+00
6	105	32	876	0.002	0.13	400	1.7E+02	0.100	58.205	Benzene (TEX similar)	1.7E+00	2.3E+00	4.0E+00
10	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.6E+00	1.6E+00	2.6E+00
10	105	32	876	0.002	0.13	400	1.7E+02	0.005	3.860	Benzene (TEX similar)	1.6E+00	1.7E+00	2.7E+00
10	105	32	876	0.002	0.13	400	1.7E+02	0.010	6.721	Benzene (TEX similar)	1.6E+00	1.8E+00	2.8E+00
10	105	32	876	0.002	0.13	400	1.7E+02	0.020	12.441	Benzene (TEX similar)	1.6E+00	1.8E+00	2.8E+00
10	105	32	876	0.002	0.13	400	1.7E+02	0.050	29.603	Benzene (TEX similar)	1.6E+00	1.8E+00	2.8E+00
10	105	32	876	0.002	0.13	400	1.7E+02	0.100	58.205	Benzene (TEX similar)	1.6E+00	1.8E+00	2.8E+00

Table 7 Migration-to-Groundwater Half Life Sensitivity Analysis

Saturated Source Thickness (ft)	Source Length (ft)	Aquifer Thickness (ft)	Hydraulic Conductivity (m/yr)	Hydraulic Gradient (m/yr)	Infiltration Rate (m/yr)	Half Life (days)	Koc	foc	Retardation Factor	Representative Compounds	Dilution Factor	Attenuation Factor	Dilution-Attenuation Factor
0	105	32	876	0.002	0.13	3	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+00	6.6E+23	1.5E+24
0	105	32	876	0.002	0.13	10	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+00	7.0E+07	1.6E+08
0	105	32	876	0.002	0.13	20	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+00	2.6E+04	6.1E+04
0	105	32	876	0.002	0.13	50	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+00	2.3E+02	5.4E+02
0	105	32	876	0.002	0.13	100	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+00	4.6E+01	1.1E+02
0	105	32	876	0.002	0.13	200	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+00	1.7E+01	4.0E+01
0	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+00	8.1E+00	1.9E+01
0	105	32	876	0.002	0.13	1000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+00	3.3E+00	7.7E+00
0	105	32	876	0.002	0.13	10000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+00	1.2E+00	2.7E+00
0	105	32	876	0.002	0.13	100000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.3E+00	1.0E+00	2.4E+00
1	105	32	876	0.002	0.13	3	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.2E+00	8.8E+00	1.9E+01
1	105	32	876	0.002	0.13	10	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.2E+00	8.8E+00	1.9E+01
1	105	32	876	0.002	0.13	20	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.2E+00	8.8E+00	1.9E+01
1	105	32	876	0.002	0.13	50	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.2E+00	8.5E+00	1.8E+01
1	105	32	876	0.002	0.13	100	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.2E+00	7.5E+00	1.6E+01
1	105	32	876	0.002	0.13	200	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.2E+00	6.1E+00	1.3E+01
1	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.2E+00	4.5E+00	9.7E+00
1	105	32	876	0.002	0.13	1000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.2E+00	2.6E+00	5.7E+00
1	105	32	876	0.002	0.13	10000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.2E+00	1.1E+00	2.5E+00
1	105	32	876	0.002	0.13	100000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.2E+00	1.0E+00	2.2E+00
3	105	32	876	0.002	0.13	3	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	3.6E+00	7.0E+00
3	105	32	876	0.002	0.13	10	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	3.6E+00	7.0E+00
3	105	32	876	0.002	0.13	20	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	3.6E+00	7.0E+00
3	105	32	876	0.002	0.13	50	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	3.6E+00	6.9E+00
3	105	32	876	0.002	0.13	100	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	3.4E+00	6.6E+00
3	105	32	876	0.002	0.13	200	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	3.1E+00	6.1E+00
3	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	2.7E+00	5.3E+00
3	105	32	876	0.002	0.13	1000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	2.0E+00	3.9E+00
3	105	32	876	0.002	0.13	10000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	1.1E+00	2.2E+00
3	105	32	876	0.002	0.13	100000	1.7E+02	0.001	1.572	Benzene (TEX similar)	2.0E+00	1.0E+00	2.0E+00
6	105	32	876	0.002	0.13	3	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.7E+00	2.3E+00	4.0E+00
6	105	32	876	0.002	0.13	10	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.7E+00	2.3E+00	4.0E+00
6	105	32	876	0.002	0.13	20	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.7E+00	2.3E+00	4.0E+00
6	105	32	876	0.002	0.13	50	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.7E+00	2.3E+00	4.0E+00
6	105	32	876	0.002	0.13	100	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.7E+00	2.2E+00	3.9E+00
6	105	32	876	0.002	0.13	200	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.7E+00	2.1E+00	3.7E+00
6	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.7E+00	2.0E+00	3.5E+00
6	105	32	876	0.002	0.13	1000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.7E+00	1.7E+00	2.9E+00
6	105	32	876	0.002	0.13	10000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.7E+00	1.1E+00	1.9E+00
6	105	32	876	0.002	0.13	100000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.7E+00	1.0E+00	1.8E+00
10	105	32	876	0.002	0.13	3	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.6E+00	1.8E+00	2.8E+00
10	105	32	876	0.002	0.13	10	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.6E+00	1.8E+00	2.8E+00
10	105	32	876	0.002	0.13	20	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.6E+00	1.8E+00	2.8E+00
10	105	32	876	0.002	0.13	50	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.6E+00	1.8E+00	2.8E+00
10	105	32	876	0.002	0.13	100	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.6E+00	1.7E+00	2.8E+00
10	105	32	876	0.002	0.13	200	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.6E+00	1.7E+00	2.7E+00
10	105	32	876	0.002	0.13	400	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.6E+00	1.6E+00	2.6E+00
10	105	32	876	0.002	0.13	1000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.6E+00	1.4E+00	2.3E+00
10	105	32	876	0.002	0.13	10000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.6E+00	1.1E+00	1.7E+00
10	105	32	876	0.002	0.13	100000	1.7E+02	0.001	1.572	Benzene (TEX similar)	1.6E+00	1.0E+00	1.6E+00

Proposed Dilution Factor Conceptual Site Conditions

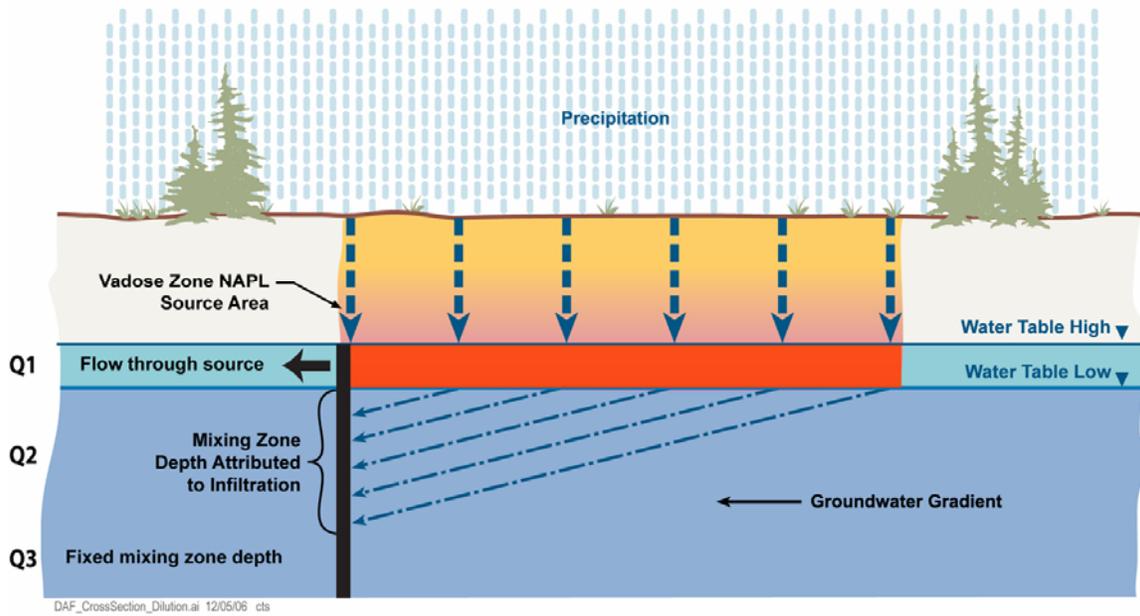
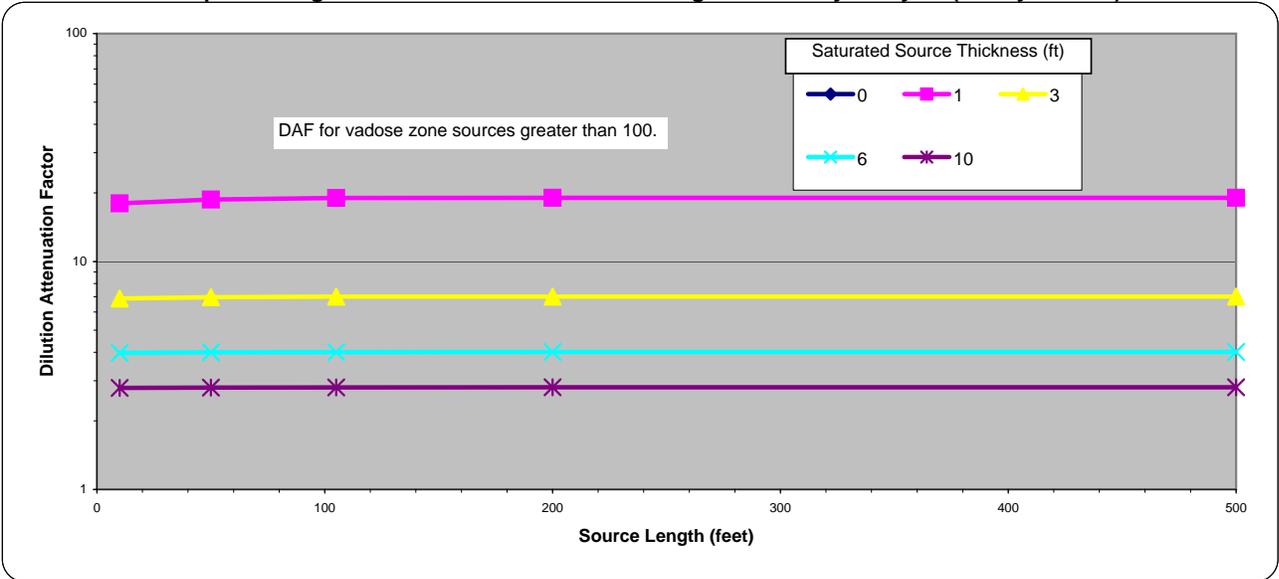
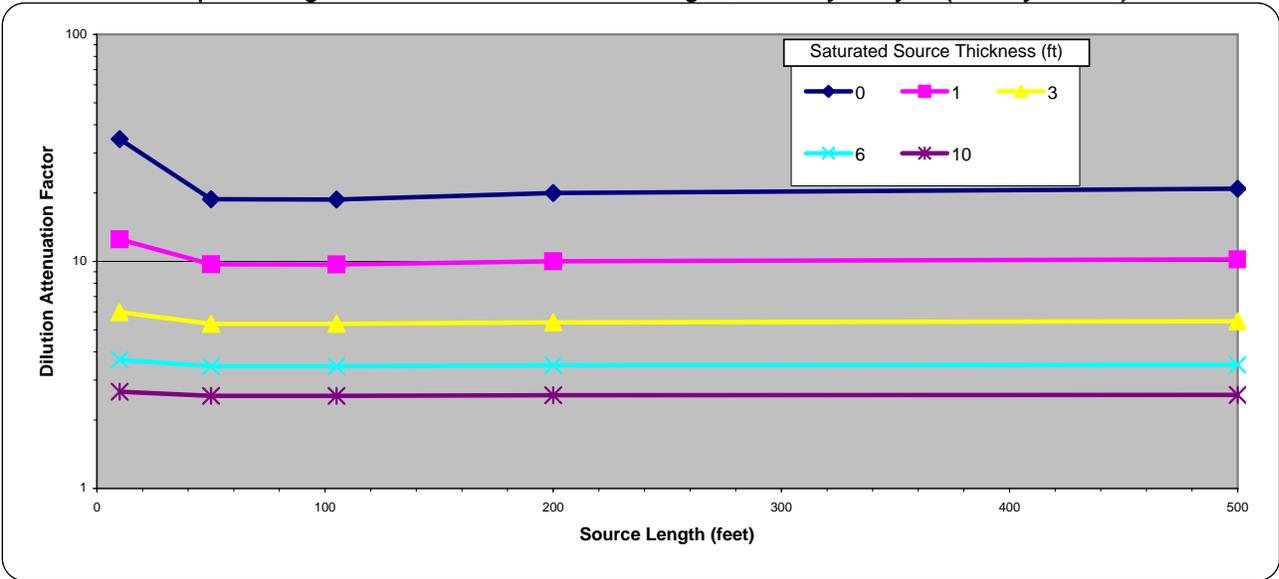


Figure 1 Proposed Dilution Attenuation Factor Conceptual Site Conditions

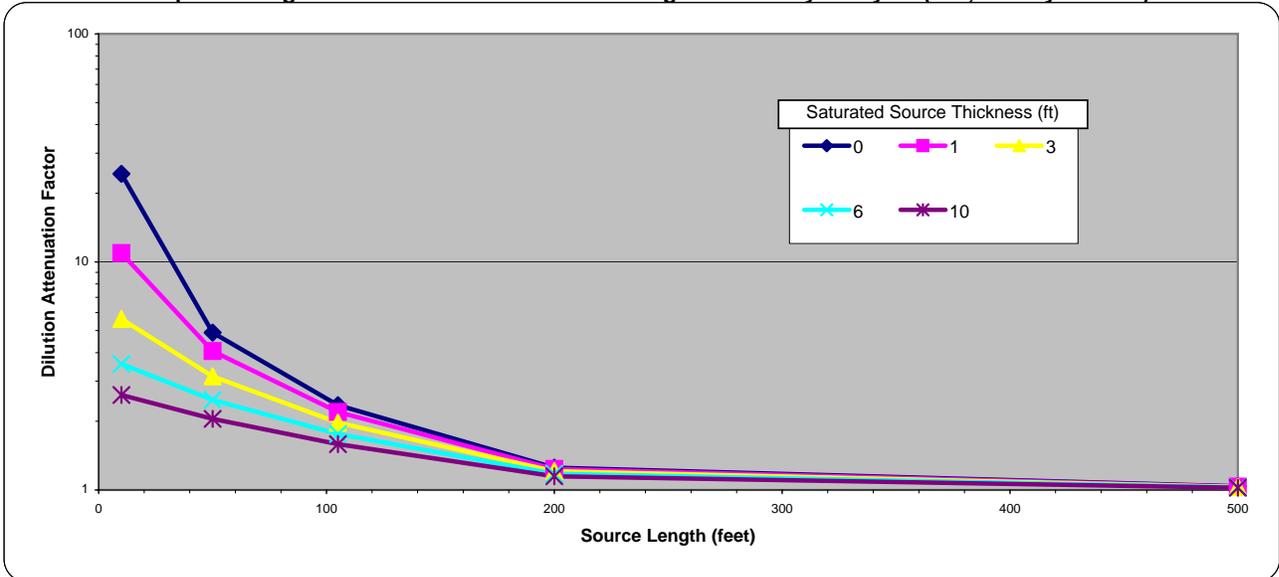
Graph 1A Migration to Groundwater Source Length Sensitivity Analysis (25 day half life)



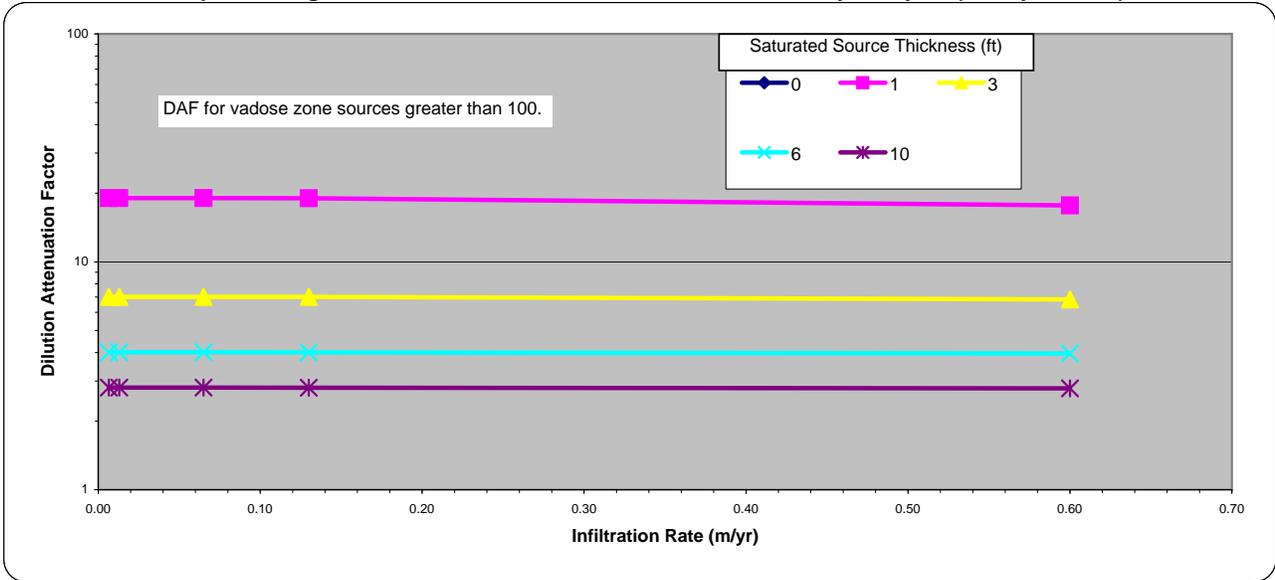
Graph 1B Migration to Groundwater Source Length Sensitivity Analysis (400 day half life)



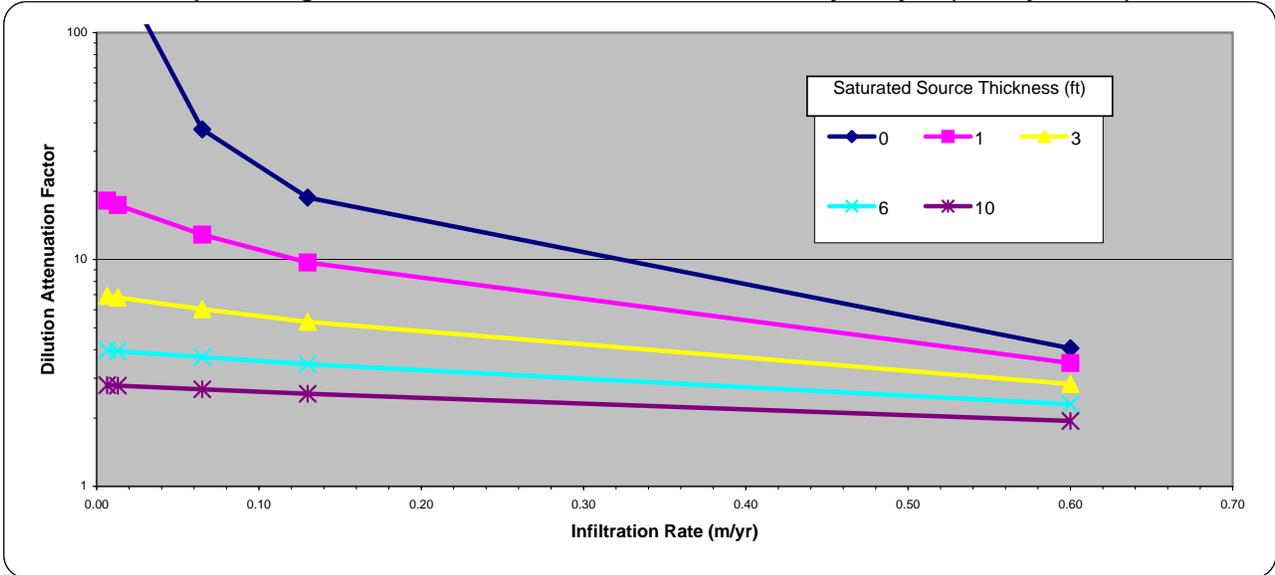
Graph 1C Migration to Groundwater Source Length Sensitivity Analysis (100,000 day half life)



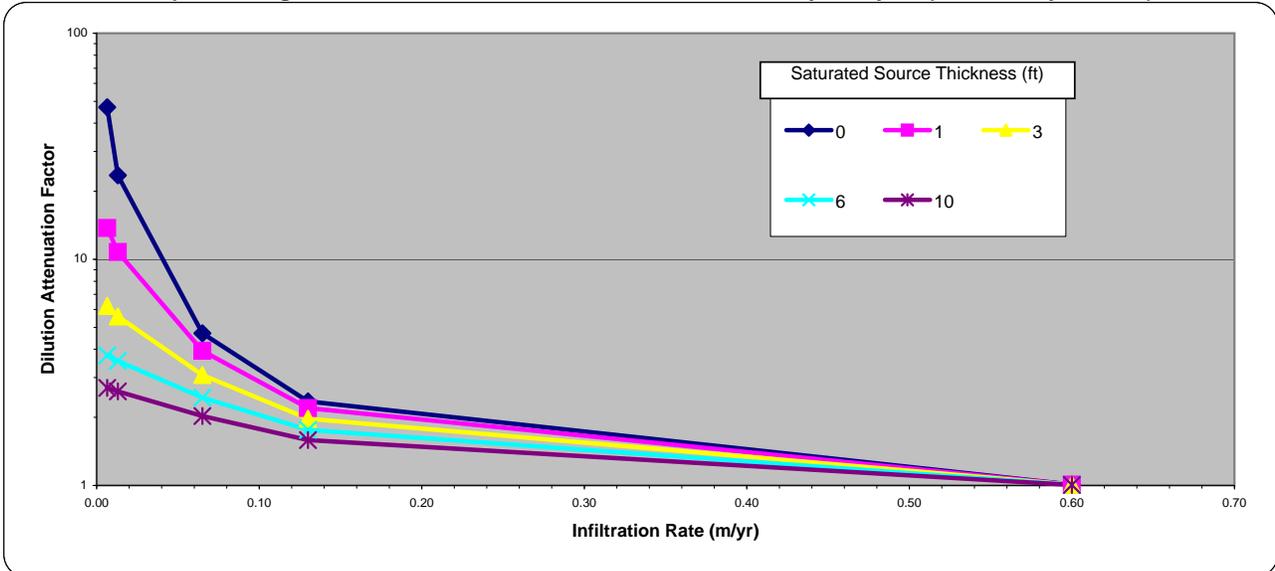
Graph 2A Migration to Groundwater Infiltration Rate Sensitivity Analysis (25 day half life)



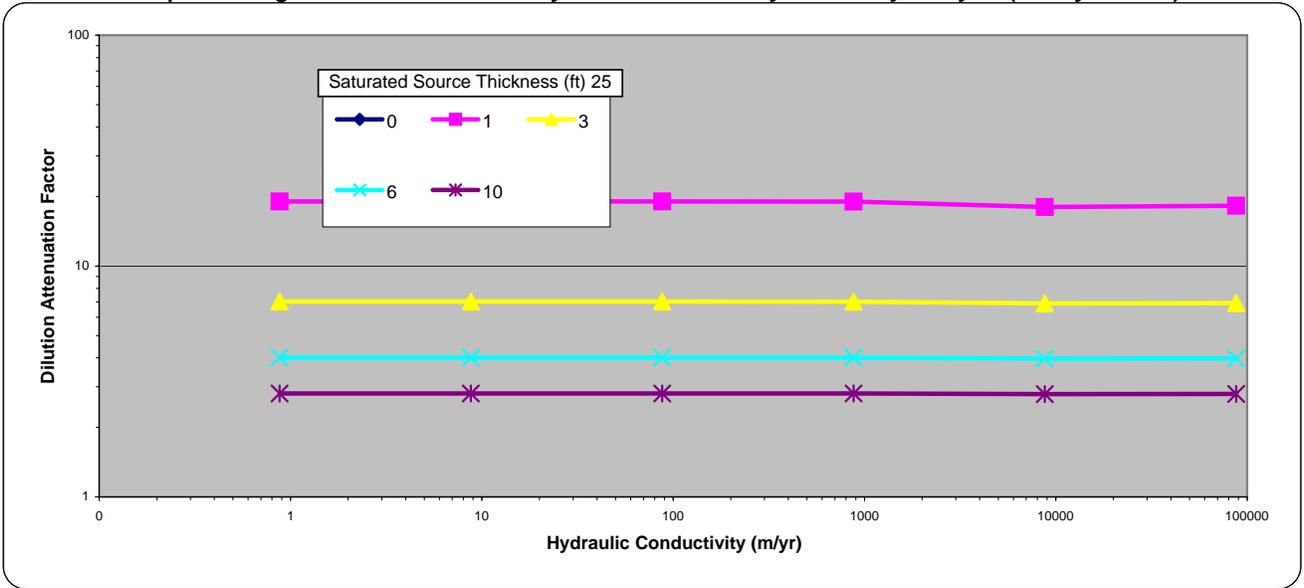
Graph 2B Migration to Groundwater Infiltration Rate Sensitivity Analysis (400 day half life)



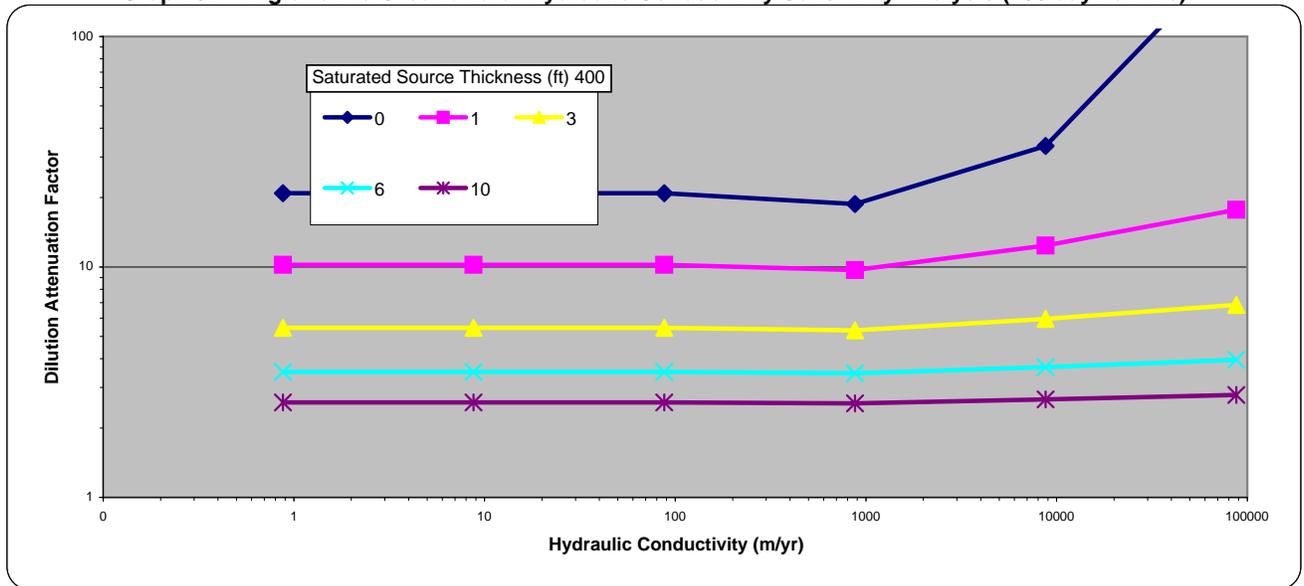
Graph 2C Migration to Groundwater Infiltration Rate Sensitivity Analysis (100,000 day half life)



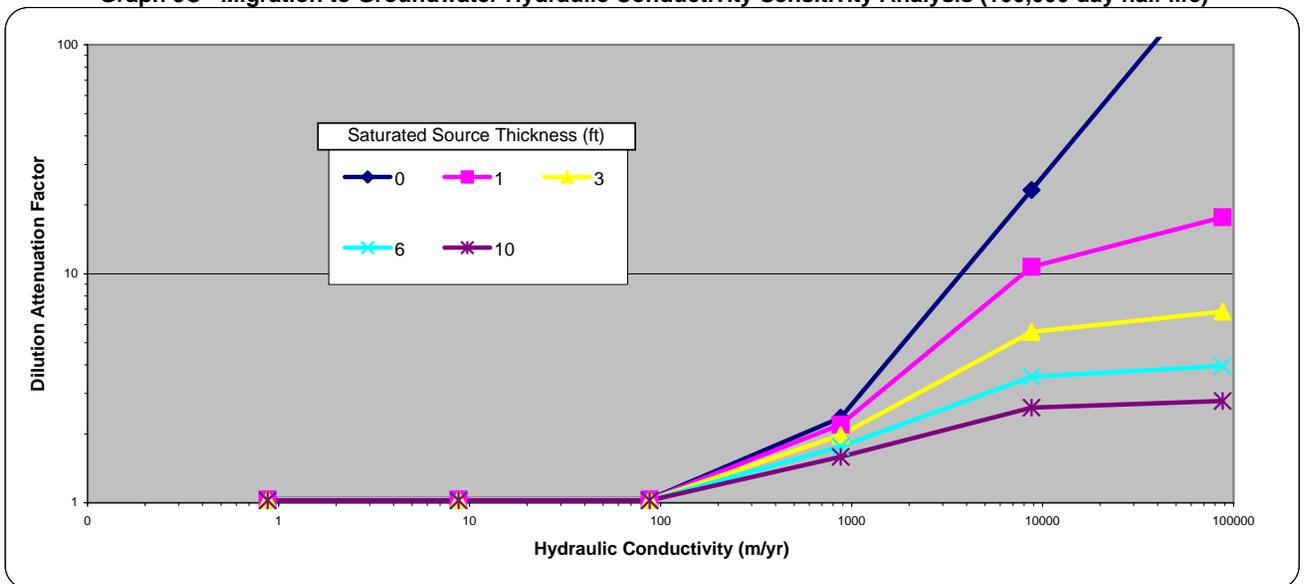
Graph 3A Migration to Groundwater Hydraulic Conductivity Sensitivity Analysis (25 day half life)



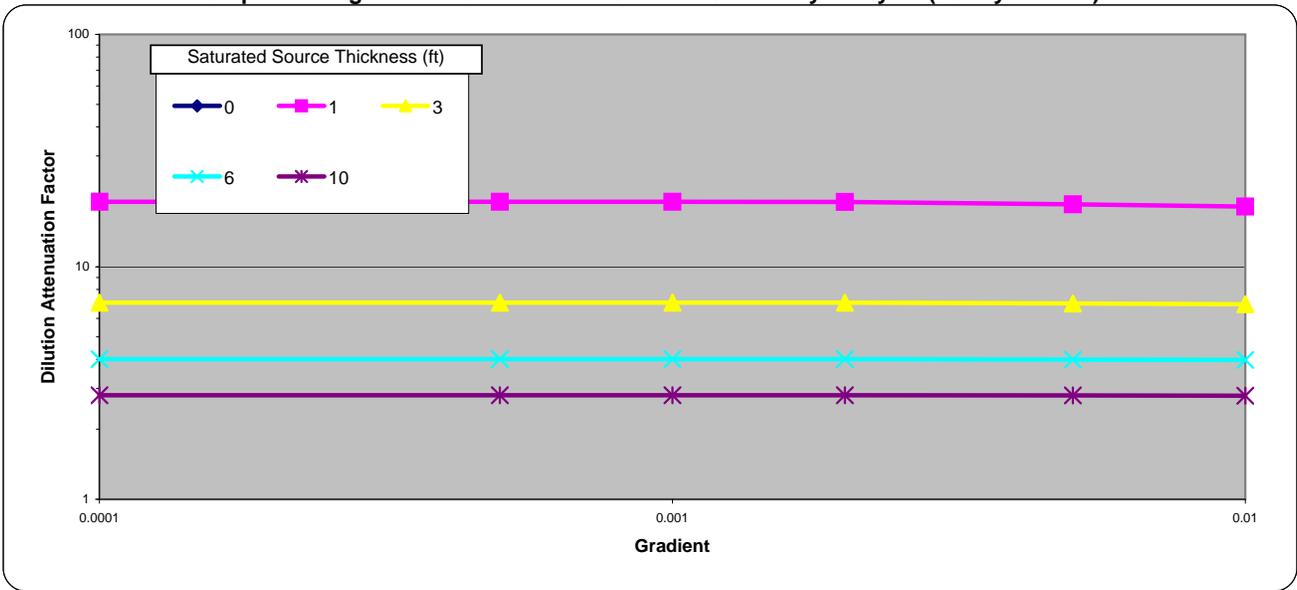
Graph 3B Migration to Groundwater Hydraulic Conductivity Sensitivity Analysis (400 day half life)



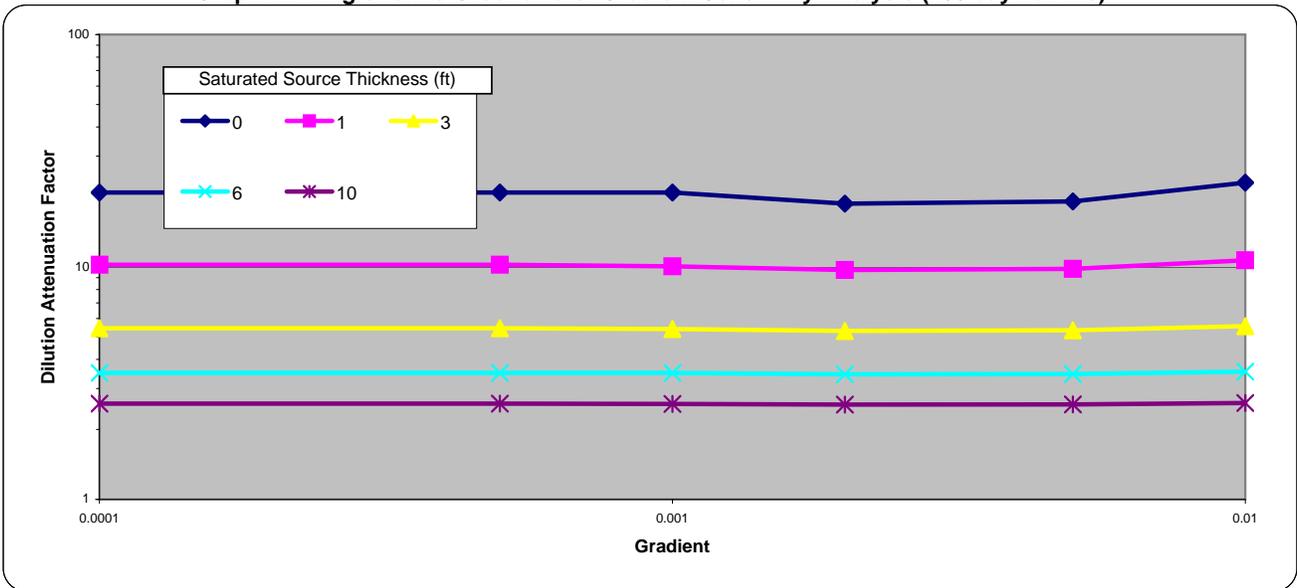
Graph 3C Migration to Groundwater Hydraulic Conductivity Sensitivity Analysis (100,000 day half life)



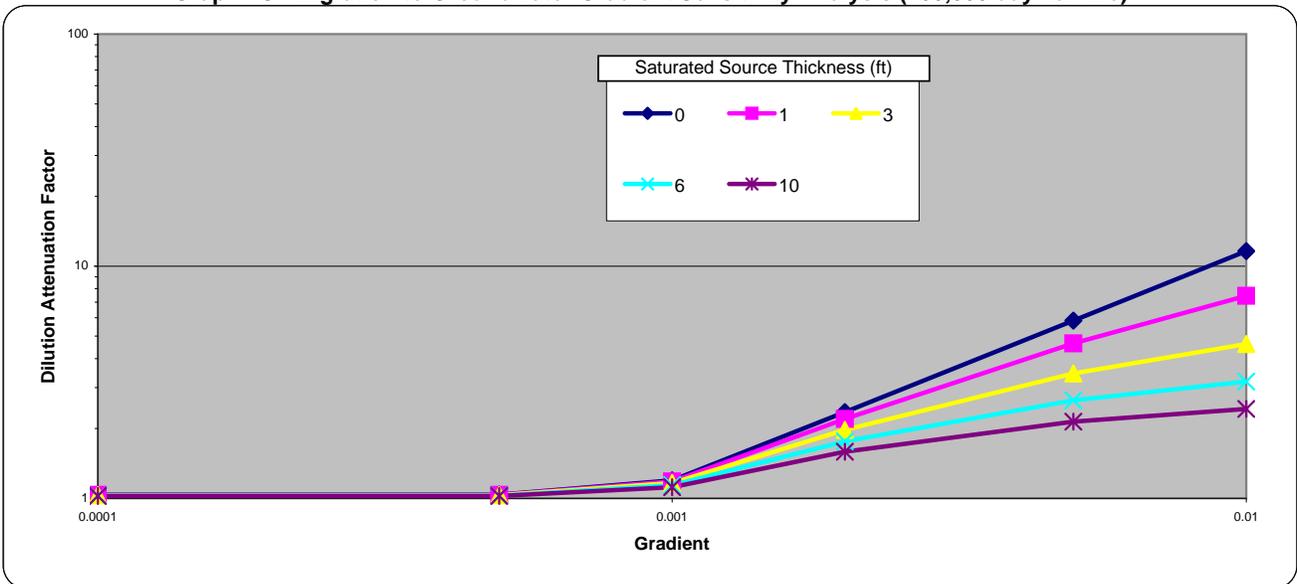
Graph 4A Migration to Groundwater Gradient Sensitivity Analysis (25 day half life)



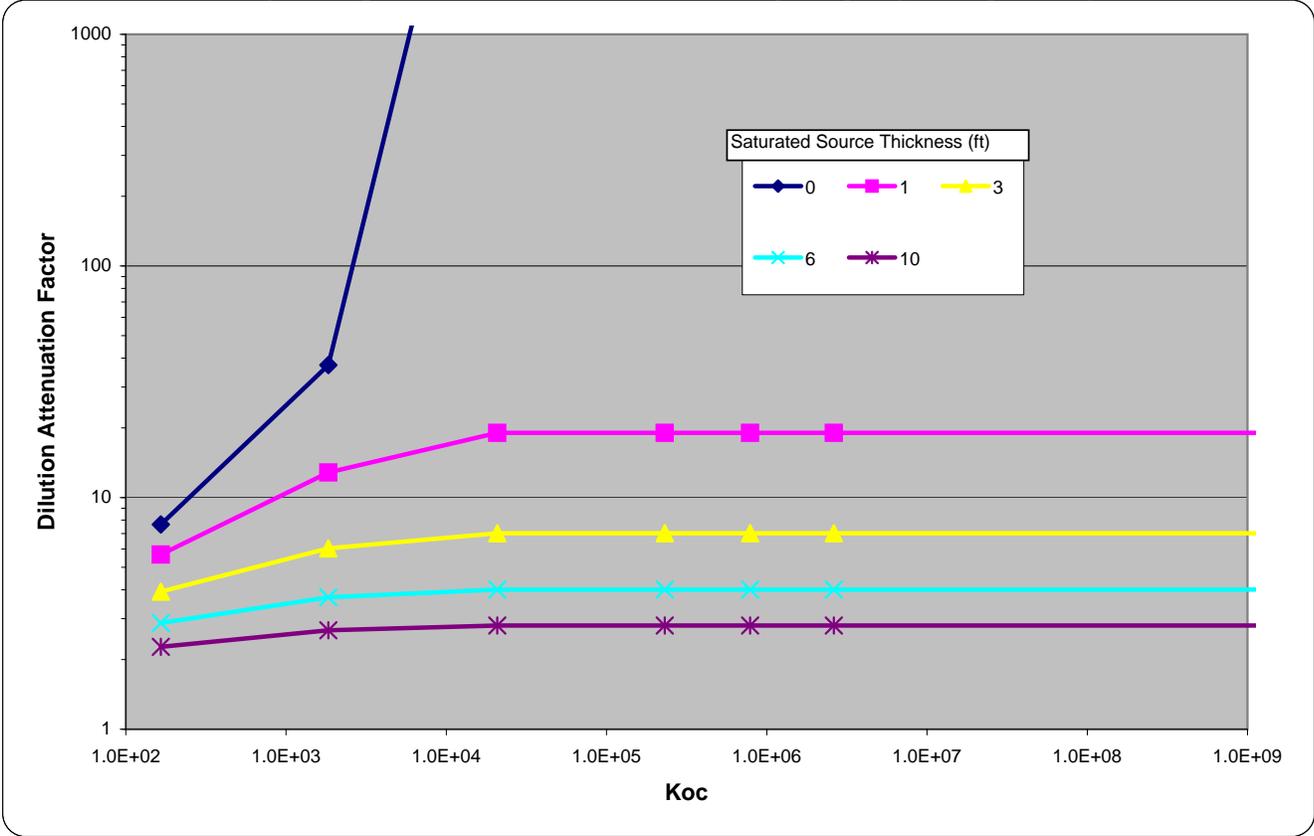
Graph 4B Migration to Groundwater Gradient Sensitivity Analysis (400 day half life)



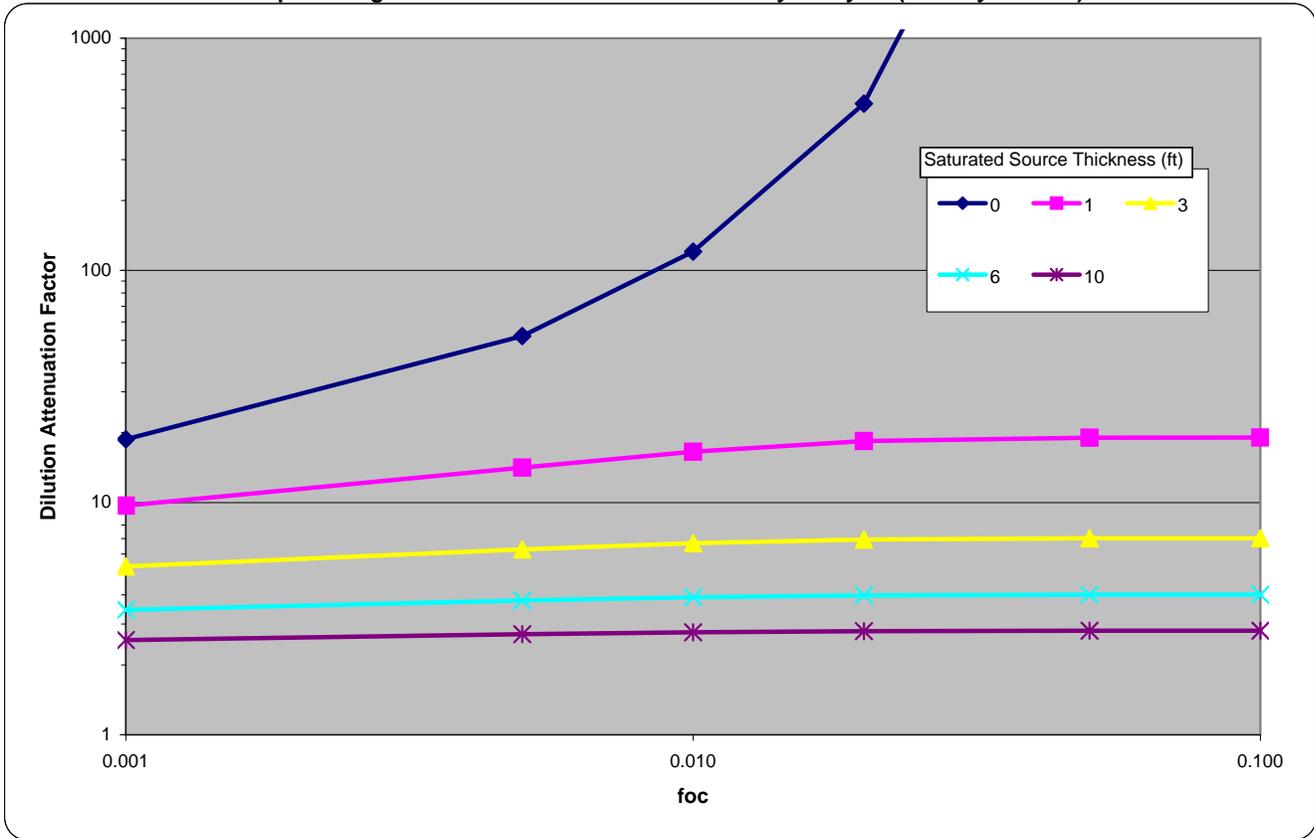
Graph 4C Migration to Groundwater Gradient Sensitivity Analysis (100,000 day half life)



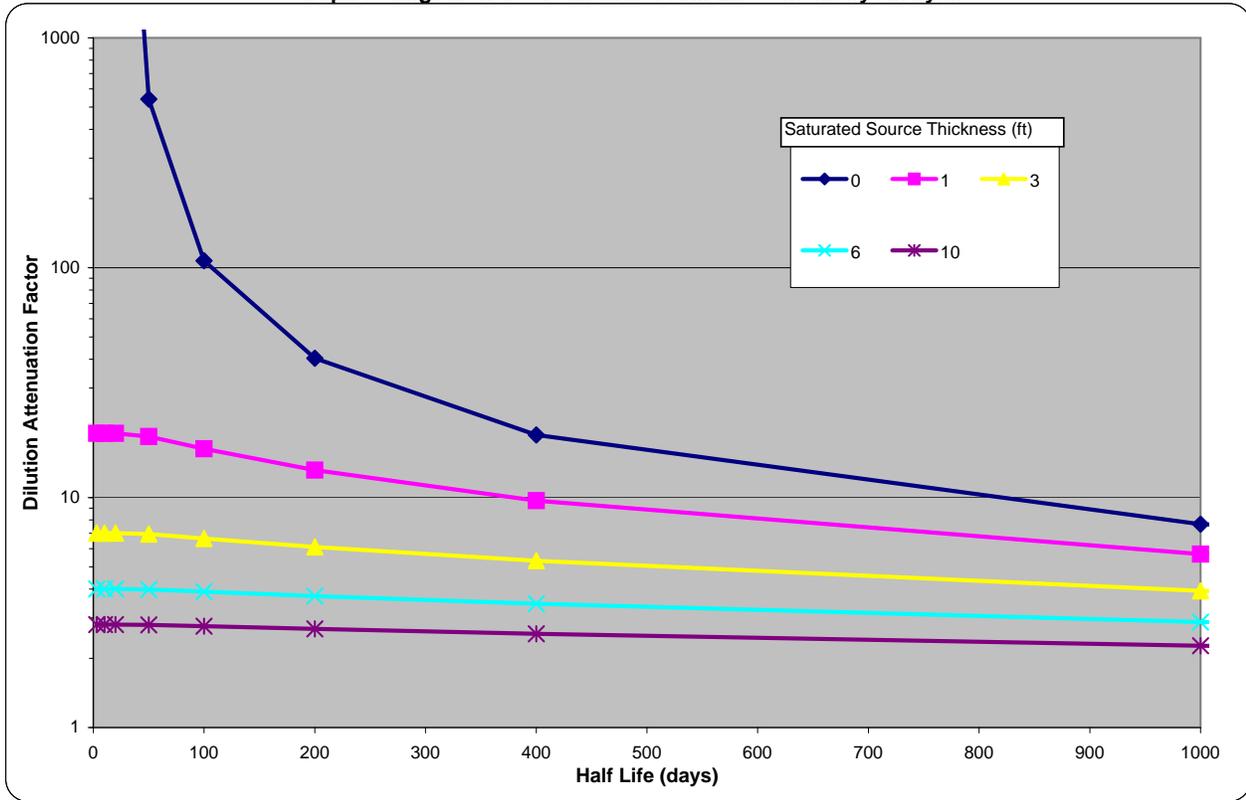
Graph 5 Migration to Groundwater Koc Sensitivity Analysis (1000 day half life)



Graph 6 Migration to Groundwater f0c Sensitivity Analysis (400 day half life)



Graph 7 Migration to Groundwater Half Life Sensitivity Analysis



Appendix C
Hydrocarbon Risk Calculator-
Calculation Summary

Hydrocarbon Risk Calculator–Calculation Summary

The calculations performed in each section of the hydrocarbon risk calculator are described in this section and documented in the hydrocarbon risk calculator. The documentation of the calculations includes the following:

- Displaying the equations for all calculations (the equations are visible by selecting individual cells in Excel)
- Using text cells to identify every calculation and listing units for each calculation
- Identifying the source document for primary calculations (for example Alaska Department of Environmental Conservation [ADEC] *Cleanup Level Guidance Document Equation #13* or U.S. Environmental Protection Agency [EPA] *Johnson and Ettinger Equation #17*)
- Making each variable in an equation an input parameter so that the variable is defined where it is input (and so that its value may be changed)
- Naming selected variables in Excel so that when the variable is used in an equation, the variable name appears instead of the cell reference (for example, the appearance of the variable names where applied to the bulk density, total porosity, water-filled porosity, target hazard quotient, and target carcinogenic risk). The list of named variables is embedded in the calculator.
- Providing a list of constants and unit conversion factors used in the calculator
- Incorporating text notes that describe the logic used in set of calculations (for example, describing how the “best” soil gas concentration is selected for the risk calculations)
- Using a consistent “parallel” equations and logic in the calculations (much of the calculator was constructed using the “fill down” function)
- Inserting comments to help describe calculations or values

All equations in the hydrocarbon risk calculator are locked. Many calculations are updated as new data are entered into the calculator; however, **the phase-partitioning and risk calculations are only updated when the “calculate button” is clicked.**

C.1 Section 1 – Hydrocarbon Concentration and Soil and Groundwater Conditions Calculations

Calculations and results are presented in Section 1 (Page 1) of the calculator and include the following:

- Summing the gasoline-range organic (GRO), diesel-range organic (DRO), and residual-range organic (RRO) concentrations to arrive at total petroleum hydrocarbon concentration for both the soil and groundwater
- Calculating the total porosity; the water-filled, air-filled, and nonaqueous phase liquid- (NAPL-) filled porosities; and the water and oil saturations. The calculations follow basic hydrologic and geotechnical parameter relationships (e.g., the porosity is calculated from the specific gravity and bulk density data).
- Calculating a dilution factor and a dilution-attenuation factor

C.2 Section 2 – Migration-to-indoor-air Model Input Parameters

Calculations in Section 2 (Page 2) of the calculator include intermediate calculations to the Johnson and Ettinger model associated primarily with soil conditions and building input parameters. The calculations used in the hydrocarbon risk calculator perform the same calculations contained in the EPA Advanced Soil Gas version of the Johnson and Ettinger model. Details on the calculations are presented in the EPA documentation (EQM, 2004).

C.3 Section 3 – Phase-Partitioning Calculations

The third section (Page 3) of the spreadsheet performs the phase-partitioning calculations and assesses whether a three- or four-phase hydrocarbon distribution is present. The cells displaying the results are highlighted in light gray. The four-phase partitioning equations require that several simultaneous equations be solved. The Excel spreadsheet defines the partitioning equations, and “Solver,” an Excel add-on feature, is used to numerically converge on the unique solution to the four-phase equations. The Excel Solver approach in the hydrocarbon risk calculator is the same as that used by the Washington State Department of Ecology and is documented in a paper by Hun Seak Park and Charles San Juan (2000). The Solver calculation is activated by clicking on the tan colored “calculate button” in Section 1. After the four-phase equations are solved with the use of Solver, the four-phase results are automatically compared to three-phase calculations and if-then statements are used to assess whether a three- or four-phase distribution is present. The three-phase calculations and all subsequent calculations do not require the Excel Solver tool. All cells and calculations are updated and saved when the calculate button is activated. The appropriate three- or four-phase distributions are then used to characterize the dissolved- and vapor-phase concentrations in the contaminated-soil source area of the subject site.

The core four-phase equations are as follows (Park and San Juan, 2000):

$$C_t^i = x_i S_i / \rho_b (H_i n_a + K_{oc}^i f_{oc} \rho_b + n_w + (MW_i n_{NAPL} / S_i \sum (x_i MW_i / \rho_i)))$$

$$\sum x_i = 1$$

$$n = n_a + n_w + n_{\text{NAPL}}$$

Where: Four phases of NAPL, pore water, pore air, soil sorbed, and total are represented by the subscripts NAPL, w, a, s, and t, respectively

C_i = concentration of component i in each of the four phases and total

K_{oc}^i = soil organic carbon to water partition coefficient of component i

f_{oc} = mass fraction of natural soil organic carbon within the soil matrix

H_i = dimensionless Henry's Law constant of component i

S_i = pure aqueous solubility of component i

x_i = mole fraction of component i in the NAPL mixture

n = total soil porosity

n_w = water-filled porosity = volumetric water content in soil

n_a = air-filled porosity = volumetric air content in soil

n_{NAPL} = NAPL-filled porosity = volumetric NAPL content

MW_i = molecular weight of component i

ρ_b = dry soil bulk density

ρ_i = density of component i in liquid form

The results of the equilibrium phase-partitioning calculations are displayed in several formats in Section 3. For example, the concentration and percent of mass in the dissolved, vapor, adsorbed, and NAPL phases is provided. This information is valuable for understanding the behavior of the different fractions. Finally, note that only a summary of the phase-partitioning calculations are presented in the hydrocarbon risk calculator printout and that intermediate calculations are to the right of the printed area.

C.4 Section 4 – Soil Direct Contact Risk

The fourth section (Page 4) of the spreadsheet calculates the soil direct contact risks for residential and industrial land use. The cells displaying the results are highlighted in tan. The bulk hydrocarbon concentration in each hydrocarbon fraction at the subject site is displayed in cells C97 to C139. Note that benzene, ethylbenzene, and naphthalene are listed twice in the soil direct contact and subsequent risk calculation results. The first listing of these compounds characterizes the non-carcinogenic risks associated with the compound; the second listing characterizes the carcinogenic risk associated with the compound. (In addition, the carcinogenic compounds are listed in bold.) The EPA (1996) and ADEC (2008) soil-screening equations are used without modification to back-calculate the bulk soil concentration that produces a hazard index of 1 for the non-carcinogenic compounds and a cancer risk of 1×10^{-5} for the carcinogenic

compounds for the hydrocarbon compounds of interest in the contaminated soil source area (benzene, toluene, ethylbenzene, and xylene [BTEX]; GRO; DRO; residual-range organics [RRO]; and polycyclic aromatic hydrocarbons [PAH]). The results of the ingestion risk calculations are displayed in cells D97 to D139 for residential sites and in cells H97 to H139 for industrial sites. Note that ingestion risk increases linearly with increasing bulk soil concentration. (The phase in which the hydrocarbon is ingested is not important). Therefore, the back-calculated soil-ingestion cleanup level is the same value whether three or four hydrocarbon phases are present. The hydrocarbon risk calculator compares the back-calculated, risk-based soil concentration to the concentration measured at the subject site to assess the “fraction of risk” created by the presence of each compound of interest:

$$\text{fraction of risk} = \text{concentration at subject site} / \text{risk-based concentration}$$

The fraction of risk calculations displayed in cells E97 to E139 and G83 to G111 for residential and industrial sites, respectively, are used in subsequent cumulative risk calculations and to screen for compliance with the regulations. A check for regulatory compliance is made by using Excel “if-then” statements as follows: If the fraction of risk for a given compound is less than 1, then the site meets the compliance criteria for that compound and the spreadsheet displays a “0.” If the fraction of risk is greater than 1, then the site does not meet regulatory criteria and the spreadsheet displays a “1” as shown in cells F97 to F139 and cells I97 to I139 for residential and industrial sites, respectively.

C.5 Section 5 – Migration-to-outdoor-air Risk

The fifth section (Page 5) of the spreadsheet calculates and displays the vapor inhalation risks for residential and industrial land use. The cells displaying the results are highlighted in light green. The EPA and ADEC three-phase soil-screening equations and the four-phase Excel Solver vapor concentrations are combined to assess the vapor inhalation risks.

The EPA and ADEC linear three-phase soil-screening equations are used to back-calculate the bulk soil concentration that produces a hazard index for the vapor inhalation pathway of 1 for the non-carcinogenic compounds and a cancer risk of 1×10^{-5} for the carcinogenic compounds. The EPA/ADEC conceptual model and equations for vapor inhalation (Figure 6) assume that volatiles in the soil diffuse into the outdoor air above the ground surface where they are mixed with uncontaminated ambient air. When back-calculating these risk-based inhalation levels, the concentrations were not capped at the soil saturation concentration limit. Note that for many hydrocarbon constituents, the three-phase equations calculate a soil concentration that is above the soil saturation concentration (C_{sat}) for the compound, which results in a back-calculated, three-phase vapor concentration that is above the maximum vapor concentration of the compound. Risk-based vapor concentrations above the maximum vapor concentration of a compound indicate that the compound cannot present a risk to human health through the vapor inhalation exposure pathway (however, the compound still contributes to cumulative risk).

The risk-based bulk soil concentration from the three-phase soil-screening equation is then used to calculate the three-phase vapor concentration (cells D149 to D1191 and G149 to G191) associated with the risk-based bulk soil concentration as follows:

$$C_a \text{ (mg/L)} = H'(C_s / (K_d + ((n_w + H' * n_a) / \rho_b)))$$

Where: C_a = compound concentration in air (milligrams per liter [mg/L])

ρ_b = soil dry bulk density (kilograms per liter [kg/L] or milligrams per cubic centimeter [mg/cm³])

K_d = soil-water partitioning coefficient (liters per kilogram [L/kg]) = $k_{oc} * f_{oc}$

n_w = water-filled porosity (L water/L soil)

H' = dimensionless Henry's Constant

n_a = air-filled porosity (L air/L soil)

The risk-based, three-phase vapor concentration is then compared to the soil vapor concentration (C149 to C191) to assess the fraction of risk created by the presence of each compound of interest:

fraction of risk = vapor concentration at subject site/ risk-based vapor concentration

The fraction of risk calculation results, displayed in cells D149 to D191 and H149 to H191 for residential and industrial sites, are used in subsequent cumulative risk calculations and are used to screen for compliance with the regulations. If the fraction of risk for a given compound is less than 1, the site meets the risk-based criteria for that compound and zero is displayed; if the fraction of risk is greater than 1, the site does not meet regulatory criteria and 1 is displayed, as shown in cells F149 to F191 and I149 to I191.

C.6 Section 6 – Migration-to-indoor-air Risk

The sixth section of the spreadsheet (Page 6) calculates and displays the migration-to-indoor-air or vapor-intrusion inhalation risks for residential and industrial land use. The cells displaying the results are highlighted in olive green. The Johnson and Ettinger model and a characterization of the soil vapor hydrocarbon concentrations are combined to assess the migration-to-indoor-air or vapor intrusion risks. The Johnson and Ettinger model is used to calculate an attenuation factor exactly as is done in the EPA "advanced soil gas" version of the Johnson and Ettinger model. Note that benzene, ethylbenzene, and naphthalene are listed twice in the vapor-intrusion risk calculations. The first entry characterizes the non-carcinogenic risk, and the second entry characterizes the carcinogenic risk associated with the compounds. This approach matches the approach used in the EPA Johnson and Ettinger soil-gas model.

The "best" measure of the soil vapor concentration in the NAPL-contaminated soil source area is shown in cells C201 to C242 and this soil vapor concentration is used in the risk calculations. These vapor concentrations are from one of the following: (1) the four-phase Solver solution for vadose zone sources, (2) a calculation based on partitioning from the groundwater data if the source is in the saturated zone, or (3) direct sub-slab soil-gas concentration measurements. Excel "if- then" statements are used to select the "best" measure of the soil vapor concentration by one of the following methods:

- If measured soil gas concentrations are collected and used as input to the model, then the measured soil gas concentrations are used in the risk calculations

- If measured soil gas concentrations are not used as input and the NAPL-contaminated soil source is entirely within the vadose zone, then the equilibrium NAPL-vapor concentrations as calculated by Solver are used in the risk calculations
- If measured soil gas concentrations are not used as input and the NAPL-contaminated soil source extends into the zone (as indicated by cell H31), then the equilibrium water-vapor concentrations calculated using the input groundwater concentrations is used in the risk calculations.

The source area vapor concentrations are multiplied by the Johnson and Ettinger attenuation factor to predict a building vapor concentration, as displayed in cells D201 to D242. Back-calculated, risk-based target concentrations for residential and industrial indoor air are listed in cells E201 to E242 and H201 to H242, respectively. (These concentrations produce a hazard index for the vapor inhalation pathway of 1 for the non-carcinogenic compounds and a cancer risk of 1×10^{-5} for the carcinogenic compounds.)

The risk-based, indoor-air vapor concentrations are then compared to the predicted indoor-air vapor concentrations to assess the fraction of risk created by the presence of each compound of interest as follows:

Fraction of risk = vapor concentration predicted to be in indoor-air / indoor-air risk-based vapor concentration

The fraction of risk calculation results, displayed in cells F201 to F242 and I201 to I242 for residential and industrial sites, respectively, are used in subsequent cumulative risk calculations and to screen for compliance with the regulations. If the fraction of risk for a given compound is less than 1, the site meets the risk-based criteria for that compound and zero is displayed; if the fraction of risk is greater than 1, the site does not meet regulatory criteria and 1 is displayed, as shown in cells G201 to G242 and J159 to J187.

C.7 Section 7 – Migration-to-Groundwater Risk (Calculated)

The seventh section (Page 7) of the spreadsheet compares the calculated, dissolved-phase equilibrium concentration in the source area soil moisture to groundwater maximum contaminant levels (MCLs) and groundwater-ingestion risk-based levels to assess the predicted migration-to-groundwater risks for residential and industrial land use. The cells displaying the migration-to-groundwater (or groundwater ingestion) results are highlighted in light blue.

The migration-to-groundwater risks are assessed using portions of the EPA and ADEC soil-screening equations combined with the four-phase Excel Solver dissolved concentrations, as shown in Figure 7 and described below.

- The equilibrium dissolved-phase concentrations, calculated by Solver from the input soil concentrations, are displayed in cells C253 to C295.
- The MCLs for compounds where available are displayed in cells D253 to D295.
- The EPA and ADEC equations for groundwater cleanup levels are used without modification to calculate a risk-based concentration for groundwater used as drinking water. These groundwater cleanup levels are based on a hazard index of 1 for the non-

carcinogenic compounds and a cancer risk of 1×10^{-5} for the carcinogenic compounds. The results for residential and industrial exposure scenarios are displayed in cells E253 to E295 and I253 to I295, respectively.

- The ADEC fixed mixing zone thickness (5.5 meters) or the thickness of the aquifer if the aquifer thickness is less than the fixed mixing zone depth is used to calculate a dilution-attenuation factor (DAF).
- A DAF is calculated as described in Appendix B.

This approach to calculating the DAF matches the approach used in the ADEC 2008 cleanup level guidance document.

- According to ADEC guidance, a target soil moisture concentration in the contaminated soil source area is calculated by multiplying the DAF by the risk-based groundwater cleanup level or MCL, whichever is lower (displayed in cells F253 to F295 for a residential site and cells J253 to J295 for an industrial site):

Target soil moisture concentration = DAF * MCL or risk-based groundwater cleanup level (if there is not an MCL)

- The fraction of risk created by the presence of each compound of interest is calculated as follows:

Fraction of risk = calculated equilibrium soil moisture concentration at subject site / risk-based or “target” soil moisture concentration

The fraction of risk calculations are displayed in cells G253 to G295 and cells K253 to K295. If the predicted fraction of risk for a given compound is less than 1, the site meets the risk-based level for that compound.

- This “target soil moisture concentration” is compared to the four-phase Excel Solver dissolved concentration to assess whether the groundwater concentrations are predicted to be within regulatory limits (assuming that the DAF characterization is accurate). The industrial site groundwater-ingestion check for compliance calculations uses residential risk-based concentrations rather than industrial risk-based concentrations. The result of the check for compliance with the regulations is displayed in cells H253 to H295 and cells L253 to L295. Note that because MCLs are below groundwater-ingestion risk-based concentrations for several compounds, it is possible to be out of compliance with regulatory concentrations but meet the groundwater-ingestion risk-based criteria.

C.8 Section 8 – Groundwater Ingestion Risk (Measured)

The eighth section (Page 8) of the spreadsheet assesses the groundwater-ingestion risk posed by the measured dissolved-phase concentrations in the source area for residential and industrial land use scenarios. The section also assesses whether the measured groundwater concentrations are in compliance with regulations (which may be valuable for compounds with MCLs below risk-based levels). The cells displaying the migration-to-groundwater results are highlighted in medium blue. Note that this section of the model uses both MCLs and groundwater-ingestion risk-based concentrations as described below:

- The measured dissolved-phase concentrations that are input to the model are displayed in cells C306 to C348.
- The MCLs for compounds where available are displayed in cells D306 to D348.
- The EPA and ADEC equations for groundwater cleanup levels are used without modification to calculate a risk-based concentration for groundwater used as drinking water. These groundwater cleanup levels are based on a hazard index of 1 for the non-carcinogenic compounds and a cancer risk of 1×10^{-5} for the carcinogenic compounds. The results for residential and industrial exposure scenarios are displayed in cells E306 to E348 and I306 to I348, respectively.
- The groundwater compliance concentrations are displayed in cells F306 to F348 for a residential site and cells J306 to J348 for an industrial site.
- For potable aquifers, the fraction of risk created by the presence of each compound or fraction is calculated as follows:

fraction of risk = measured groundwater concentration at subject site / risk-based groundwater concentration

The fraction of risk calculations for residential and industrial sites, are displayed in cells G306 to G348 and cells K306 to K348, respectively. If the predicted fraction of risk for a given compound is less than 1, the site meets the risk-based level for that compound. Note that the groundwater-ingestion risk-based concentration (which is often different than the MCL) is used in the fraction of risk calculation.

For non-potable aquifers, the fraction of risk is listed as zero for all compounds and fractions because, by definition, the aquifer and groundwater will not and/or cannot be used as a drinking water source.

A check for regulatory compliance is made by comparing the “groundwater compliance concentration” to the measured dissolved concentration to assess whether the groundwater concentrations are within regulatory limits. The industrial site groundwater-ingestion check for compliance calculations uses residential risk-based concentrations rather than industrial risk-based concentrations. The result of the check for compliance with the regulations is displayed in cells H306 to H348 and cells L306 to L348. If the measured groundwater concentration meets the compliance criteria for that compound, zero is displayed; if the measured groundwater concentration does not meet the compliance criteria for that compound, 1 is displayed.

C.9 Section 9 – Potential Cumulative Risk Assuming All Pathways Complete

The ninth section (Page 9) of the spreadsheet assesses the cumulative risks associated with fuel hydrocarbon compounds that may be expected if the soil-ingestion, migration-to-outdoor-air, migration-to-indoor-air, and groundwater-ingestion exposure routes were complete at the subject site. The term “potential cumulative risk” is used to acknowledge the risk calculations are based on numerous assumptions, such as the exposure factors, toxicities, and fate and transport characterizations. The cells displaying the potential cumulative risk by all pathways

are highlighted in purple. Cells C359 to F401 (for residential sites) and I359 to L401 (for industrial sites) summarize the fraction of risk values calculated for the soil-ingestion, migration-to-outdoor-air, migration-to-indoor-air, and groundwater-ingestion pathways. The cumulative risk for each compound is calculated as the sum of fraction of risk values associated with each pathway for that compound, as shown in cells G359 to G401 and M359 to M401 for residential and industrial sites, respectively. The cumulative carcinogenic risks are then calculated by summing risk associated with the carcinogenic compounds as shown in cells G402 and M402 for residential and industrial sites, respectively. The cumulative non-carcinogenic risks are then calculated by summing risk associated with the non-carcinogenic compounds, as shown in cells G403 and M403 for residential and industrial sites, respectively. Consistent with ADEC policy, the hydrocarbon risk calculator uses measured dissolved-phase concentrations, not dissolved-phase concentrations calculated by the spreadsheet model, to assess the groundwater-ingestion risk. Also, consistent with guidance documents (ADEC, 2002), the risks associated with the GRO, DRO, and RRO aromatics and aliphatics are not included in the cumulative risk calculation. According to the contaminated site regulations, the non-carcinogenic and carcinogenic cumulative risks are acceptable if the cumulative non-carcinogenic fraction of risk is less than 1 and the cumulative carcinogenic fraction of risk is less than 1. (The carcinogenic risk has been normalized. The carcinogenic risk level may be calculated by multiplying the fraction of carcinogenic risk by the acceptable carcinogenic risk level — 1×10^{-5} .) A check for compliance with human health risk criteria is displayed in cells H359 to H401 and cells N359 to N401. If the cumulative risk meets the compliance criteria, zero is displayed; if the measured groundwater concentration does not meet the compliance criteria for that compound, 1 is displayed.

C.10 Section 10 – Potential Cumulative Risk for Pathways Complete at Present Time

The tenth section (Page 10) of the hydrocarbon risk calculator assesses the cumulative risks associated with all compounds and all exposure routes that are complete at the site at the present time (the time the report is prepared). The cells displaying the cumulative risks for pathways complete at the present time are highlighted in gold. The section of the spreadsheet containing the cumulative risks for pathways complete at the present time is laid out identical to the preceding section (cumulative risk assuming all pathways are complete). The values in the cumulative risks for pathways complete at the present time are calculated as the values in the previous section multiplied by 1 if the pathway is complete at the present time, or by a zero if the pathway is not complete at the present time. The pathways complete at the present time are input to the calculator in the gold block of cells in the data input section of the calculator (cells K11 to K15). The purpose of calculating the cumulative risk for pathways complete at the present time is to understand whether current site conditions present an acceptable or unacceptable risk, which is valuable for prioritizing remedial and/or risk management actions and for placing the site in a site status category. Note that if all pathways are complete at the present time, then the hydrocarbon risk calculator sections titled “cumulative risk assuming all pathways are complete” and “cumulative risk at the present time” show the same risk values. A check for compliance with human health risk criteria is displayed in cells H411 to H453 and cells N411 to N453. If the cumulative risk meets the compliance criteria, zero is displayed; if the

measured groundwater concentration does not meet the compliance criteria for that compound, 1 is displayed.

C.11 Section 11 – Partitioning into Surface Water and Groundwater

The eleventh section (Page 11) of the hydrocarbon risk calculator assesses whether contaminated soil from the site has the potential to partition into groundwater or surface water at concentrations exceeding ADEC Table C levels or the ambient water quality criteria. To make these assessments, the dissolved-phase equilibrium concentration calculated from the input soil concentrations or the measured groundwater concentration (depending on whether the source is in the vadose or saturated zones) is compared to the Table C risk based concentrations, MCLs and the ambient water quality criteria using “if-then” statements. If soil has the potential to cause a compound to exceed a regulatory level, then 1 is printed in the column. If the soil does not have the potential to cause a compound to exceed a regulatory level, then zero is printed in the column. The information could be used to assess whether the soil can be transported to another site without causing a water quality criteria to be exceeded and to assign a site closeout status (provided human health and environmental risk criteria are met) as described in the paper *Proposed Environmental Site Closeout Concepts, Criteria, and Definitions* (Geosphere and CH2M HILL, 2006). The partitioning into groundwater and surface water section is highlighted in turquoise. Data displayed in the partitioning into groundwater and surface water section include the following:

- The dissolved-phase equilibrium concentrations for each hydrocarbon fraction as calculated from the input soil concentrations are printed in cells C463 to C504. The measured groundwater concentrations (from the input data) are listed in cells D463 to D504. The MCLs or risk-based groundwater-ingestion criteria are listed in cells E463 to E504.
- Cells F463 to F504 could be used to assess whether soil from the subject site could be used as vadose zone fill at another location by comparing (1) the equilibrium partitioning concentration to the target soil moisture concentration (i.e., the MCL or risk-based groundwater concentration multiplied by the DAF) if the subject site is a vadose zone spill site (NAPL is only present in the vadose zone); or (2) the measured groundwater concentration to the MCL or risk concentration if the subject spill site is a saturated zone site (i.e., NAPL is present in the saturated zone). The differing criteria for vadose and saturated spill sites are used because most existing sites are interpreted to be saturated zone spill sites and measured groundwater concentrations tend to have lower detection limits and fewer censored values than soils data. Consequently, measured groundwater concentrations are interpreted to provide a better measure of the concentration when a compound is present at low concentrations. If the soil can be used as vadose zone fill, zero is printed in the column; if the soil cannot be used as vadose zone fill, 1 is printed the column.
- Cells G463 to G504 could be used to assess whether soil from the subject site could be used as saturated zone fill at another location by comparing (1) the dissolved-phase equilibrium partitioning concentration to the MCL or risk-based concentration (without considering the DAF) if subject site is a vadose zone spill site, or (2) the measured groundwater concentration to the MCL or risk concentration if the subject spill site is a saturated zone

site. If the soil can be used as saturated zone fill, zero is printed in the column, and if the soil cannot be used as saturated zone fill, 1 is printed the column.

- The ADEC ambient water quality criteria addressing fuel hydrocarbons are listed in cells H463 to H504. The total aromatic hydrocarbon (TAH) concentration and the total aqueous hydrocarbon (TAqH) concentration are calculated as the sum of the BTEX and sum of the BTEX and PAH concentrations, respectively.
- Cells I463 to I504 could be used to assess whether soil from the subject site could be used as fill in a surface water body by comparing (1) the equilibrium partitioning concentration to the surface water criteria (without considering the DAF) if subject site is a vadose zone spill site, or (2) the measured groundwater concentration to the surface water criteria if the subject spill site is a saturated zone site. If the soil can be used as fill in surface water body, zero is printed in the column; if the soil cannot be used as fill in surface water body, 1 is printed the column.

C.12 Section 12 – Site Status Summary

The twelfth and final section (Page 12) of the hydrocarbon risk calculator summarizes the site status based on the current written regulations and describes limitations on the offsite transport of the contaminated soil. The spreadsheet displays the cumulative human health carcinogenic and non-carcinogenic risks, assuming that all pathways are complete (cells C514 and C515); the cumulative human health carcinogenic and non-carcinogenic risks for the pathways that are complete at the present time (cells C516 and C517); and compliance with aromatic and aliphatic risk criteria for GRO, DRO, and RRO (cells D519 to H524 and D525).

The spreadsheet then uses “if-then” statements to print a statement that indicates the following:

- Whether risk criteria have been met (cell A526)
- Whether migration-to-groundwater criteria have been met (cell A527)
- Description of the potential to use soils from the subject site as fill at other locations (cells A529 to A531)
- An alert to the users on the possible presence of DRO polar compounds and on the presence of total DRO in groundwater above the level listed in Title 18, Chapter 75, Table C, of the *Alaska Administrative Code* (cells A532 and A534)

C13 References

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