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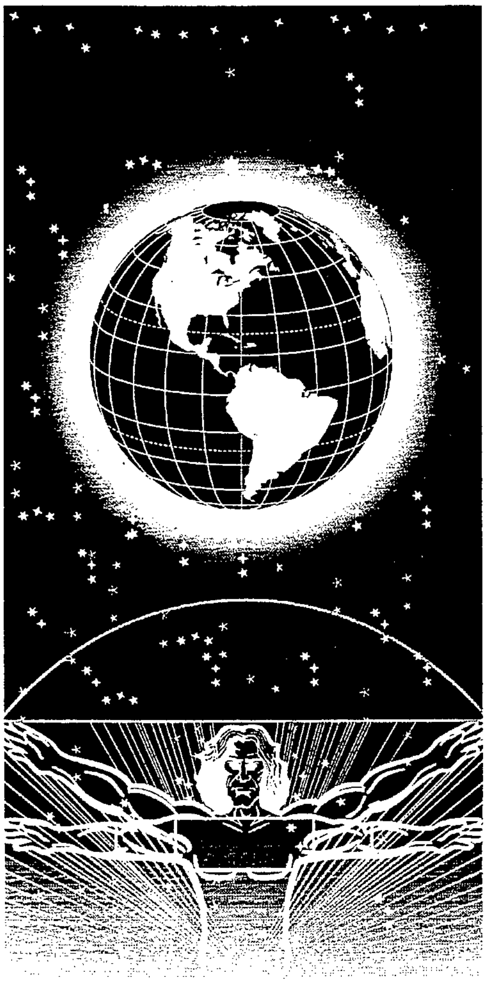

UNITED STATES AIR FORCE RESEARCH LABORATORY

TPH CRITERIA WORKING GROUP FIELD DEMONSTRATION: MISAWA AIR BASE, JAPAN

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FOR THE DIRECTOR

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Misawa Air Base, Japan, has an ongoing investigative effort to characterize the extent of petroleum soil contamination related to Tank Farm 2. During the period or 18 to 19 August 1998, soil and water samples were collected through a collaborative effort between the base, Air Force Center of Environmental Excellence and the Environmental Protection Agency Kerr Laboratory. In parallel to that effort, composites of nine soil samples were provided for this demonstration. These composites were analyzed by the Direct Method (developed by the Total Petroleum Hydrocarbon Criteria Working Group). The analytical results were used to develop example Tier 1 Risk Based Corrective Action clean-up levels.

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PREFACE

This effort was performed by Operational Technologies Corporation (OpTech) under U.S. Air Force Contract Number F41624-94-D-9003/008. OpTech activities were conducted under the Project Management of Mr. Erik Vermulen, 1370 North Fairfield Road, Suite A, Beavercreek, Ohio 45432. Lt Col (select) Steve Channel of the Operational Toxicology Branch, Human Effectiveness Directorate, Air Force Research Laboratory (AFRL/HEST) at Wright-Patterson Air Force Base (AFB), Ohio, served as contract monitor and Major Wade Weisman served as technical director.

The authors gratefully acknowledge Mr. Arthur Chan, Chief of the Engineering Flight, 35th Civil Engineering Squadron, and Capt Joel Almosara, Bioenvironmental Engineer, Misawa AB for their assistance in obtaining the background information on this site. Jerry Hansen, P.E., Air Force Center of Environmental Excellence, Brooks AFB, is acknowledged for his assistance at obtaining geotechnical information from the site and coordinating this effort; and Don Kampbell at the U.S. Environmental Protection Agency Kerr Laboratory, Ada, Oklahoma, for his assistance in obtaining samples. The authors also acknowledge Richard Entz and Del Schumaker of Lancaster Laboratories, Lancaster, Pennsylvania, for analytical results.

LIST OF ABBREVIATIONS AND ACRONYMS

AFCEE	Air Force Center for Environmental Excellence
atm	atmosphere
ASTM	American Society for Testing and Materials
bgs	below ground surface
BES	Brewer Environmental Services
BTEX	Benzene, Toluene, Ethylbenzene and Xylenes
cm^3	cubic centimeter
C_{sat}	soil saturation Concentration
EC	Effective Carbon number of chemical molecule
EPA	Environmental Protection Agency
FID	Flame Ionization Detector
ft	feet
g	gram
GC	Gas Chromatograph
HI	Hazard Index
HQ	Hazard Quotient
kg	kilogram
K_{oc}	carbon-water sorption coefficient
L	liter
MAB	Misawa Air Base
mg	milligram
mol	mole
mL	milliliter
NAPL	Non-Aqueous Phase Liquid
PAH	Polycyclic Aromatic Hydrocarbon
PF	Partition Factor
RBCA	Risk Based Corrective Action
RBSL	Risk Based Screening Level
RES	Residual Saturation
RfD	Reference Dose
TF2	Tank Farm 2
TPH	Total Petroleum Hydrocarbon
TPHCWG	Total Petroleum Hydrocarbon Criteria Working Group

TPH CRITERIA WORKING GROUP FIELD DEMONSTRATION: MISAWA AIR BASE, JAPAN

1.0 INTRODUCTION

Misawa Air Base, Japan, has an ongoing effort to characterize the vertical and horizontal extent of previous petroleum releases around jet fuel storage tanks located on the eastern section of the installation. This site, known as Tank Farm 2 (TF2), has been the subject of prior studies to characterize the extent of contamination. Currently, a cooperative effort between the Air Force Center of Environmental Excellence (AFCEE) and the U.S. Environmental Protection Agency (EPA) Kerr Laboratory exists to use innovative techniques to characterize the site. In cooperation with this effort, a demonstration of a Tier 1 human health risk assessment using the methodology of the Total Petroleum Hydrocarbon Criteria Working Group (TPHCWG or Working Group) was applied. This demonstration, sponsored by the Air Force Research Laboratory, Human Effectiveness Directorate, Toxicology Branch (AFRL/HEST), provided analysis of the soil samples by the Working Group Direct Methodology and assessment of the results using Risk Based Corrective Action (RBCA) procedures.

1.1 Objectives

This work is part of a series of field demonstrations to assess the effectiveness of the Working Group approach for evaluating different types of weathered fuel spills in various soil types. To develop an example risk-based soil clean-up criteria, three composite soil samples collected August 18-19, 1998 were analyzed by the Working Group's recommended analytical method (the Direct Method). The Direct Method groups the petroleum present in terms of 13 total petroleum hydrocarbon (TPH) fractions. The analytical results for the fractions were then used in simple fate and transport models for soil exposure pathways provided in the RBCA guidance document (ASTM, 1995). From these calculations, human health risk-based screening values, were determined using ASTM RBCA default assumptions consistent with US EPA Risk Assessment Guidance For Superfund (RAGS). The primary goals of this study were to:

1. Calculate Tier 1 risk-based screening levels (RBSLs) using the TPH fractionation results from a limited number of samples.
2. Evaluate the applicability of the Working Group approach for a site such as TF2.

It is important to note that this analysis was not intended for use in modifying the current TPH cleanup criteria established for the site. These determinations have as their basis, toxicity assessment methodology and risk assessment determination consistent with the US EPA. If EPA guidance is not applicable for making decisions at the site, then the Working Group approach would likewise not be applicable. The results of this study may provide added information on the potential risks from contaminated soil pathways. However, due to the limited number of samples available and the fact that these samples were composited from various locations, the RBSLs calculated may not be representative of soil criteria for TF2 that is protective of human health. In addition, the approach only assesses risk from soil pathways. The simple RBCA fate and transport models assess transport of contaminants from soil to other media, but do not address groundwater transport and its associated risk. Uncertainties of this demonstration are discussed later.

1.2 Overview of Working Group Approach

The Working Group approach is incorporated into the RBCA framework, which integrates site assessment with U.S. EPA-recommended risk assessment practices. The elements of a risk assessment include: characterization of the source contamination, identification of pathways through which contaminants move in the environment, identification of existing and potential receptors and assessment of exposure (ASTM, 1995).

These elements are incorporated into a tiered approach that involves increasingly site-specific levels of data collection and analysis. The initial tier, Tier 1, uses conservative default assumptions and models, some of which are replaced in later tiers (i.e., Tier 2 and 3) by less conservative, site-specific assumptions and models. The soil cleanup goals defined for a later tier may be less costly to achieve than those defined by the previous tier. The user reviews the cleanup goals and decides if the cost of conducting the additional site-specific analyses for the next tier are warranted by the potential reduction in cost associated with a reduced remediation action plan. Hence, the tiered approach is often more cost-effective than traditional approaches under which all sites, regardless of site-specific conditions, are required to conform to uniform standards and procedures.

Presently the Working Group approach focuses only on human health, addressing both carcinogenic and non-carcinogenic risks. The approach recognizes that TPH is comprised of different types or classes of hydrocarbons that differ in chemical structure. The Working Group approach relies on the separation of petroleum into 13 separate fractions, listed in Table 1-1. These fractions are based upon the physical structure of the compounds (i.e., aromatic or aliphatic) and the "equivalent carbon (EC) number," which is a function of boiling point, and are determined by the retention time on a gas chromatograph (GC) column relative to n-alkanes of known carbon number. The fractions have been assigned specific toxicological, fate and transport characteristics that are based upon an extensive review of available data for individual compounds or for petroleum mixtures which are representative of the fraction.

Within a framework such as the American Society for Testing and Materials (ASTM) RBCA, the toxicity, fate and transport information defined by the Working Group can be used to perform a risk-based analysis of each fraction within the petroleum mixture. The risk associated with the "whole TPH" mixture and the soil and groundwater criteria for the "whole TPH" mixture are then determined by combining the risks associated with individual fractions in accordance with their percent composition in the TPH mixture. A brief discussion of the Working Group approach is provided in Section 3 of this document.

TABLE 1-1 WORKING GROUP AROMATIC AND ALIPHATIC FRACTIONS

Aromatic Fraction	Aliphatic Fraction
EC 5–7 (Benzene)	EC 5–6
EC >7–8 (Toluene)	EC 6–8
EC >8–10	EC >8–10
EC >10–12	EC >10–12
EC >12–16	EC >12–16
EC >16–21	EC >16–21
EC >21–35	

Note: EC - equivalent carbon fractions are determined by the retention time on a GC column, relative to n-alkane compounds of known carbon number (TPHCWG, 1998a)

1.3 Environmental Setting

Misawa Air Base (MAB) is located in the northeastern section of Honshu, Japan's largest island. MAB is bounded by Lakes Ogawura and Anenuma to the northwest and west, respectively, and by the city Misawa-Shi to the south. The nearest large city, Hachinohe, is a port about 25 km south of MAB. Residential and farming communities are prevalent in the MAB area.

MAB has been an airfield and operations center for the U.S. armed forces since shortly after World War II. MAB is currently controlled by the U.S. Air Force 35th Fighter Wing, but is tenanted by U.S. Army, Navy and Marine units. MAB is also home to the Japan Air Self Defense Forces (JASDF) and its 3rd Air Wing. Facilities include administrative and command offices, a runway and taxiways, hangars, maintenance shops and aircraft refueling systems.

TF2 is located at the eastern border of MAB and is bordered to the west by the JASDF main compound. Taxiways for the 10,000 ft runway are north of TF2. Adjacent to the east is Misawa Airport. Two fuel hydrant systems were located in TF2 and the JASDF area which are not present now. Drawings and photos from 1959, 1968 and 1970 picture above ground tanks and piping within containment dikes; the hydrant systems were not shown in 1987 drawings. Whether the piping from the hydrant systems was removed or remained in place is not known. Photographs of the tanks show staining along riveted joints, settling or deformation of tanks and a repaired crack near the bottom of a tank. In 1955, a 400,000 gallon tank exploded and in 1968, earthquake damaged tanks. Additionally, former approved fuel handling practices, including tank water-draws (i.e., the practice of draining accumulated water from the tank through a valve at the bottom, until pure fuel drains onto the ground), contributed to the current fuel contamination.

1.4 Geology

The general geology of the MAB area is characterized as more than 100 ft of unconsolidated sediments, over bedrock units. Specifically, the Upper Noheji Formation is a 20 ft layer of unconsolidated sand, silt and clay sediments over a 100 ft thick well-sorted sand bed. Underneath, the Middle Noheji Formation is a 25 to 50 ft layer of siltstone and claystone. The Lower Noheji Formation consists of sandstone and conglomerate, and is about 150 ft thick. Underlying the Lower Noheji is the Katti Formation, a 2000 ft thick layer primarily comprised of lower permeability siltstone and sandstone, with some permeable sandstone and shell strata.

Sampling activities confirmed a relatively uniform geology with only minor local variations at the TF2 site. The surficial soil was a moist to wet, yellow to orange, poorly sorted, fine-grained sand with silty and sometimes clayey components. From 12 to 29 feet below ground surface, the sand was moist and yellow-orange, reddish or gray-brown. This rounded, fine to very fine-grained and well sorted (i.e., fairly uniform) sand layer was imbedded with lenses of medium to coarse-grained sand. Groundwater was encountered at 25 to 32 feet below ground surface (bgs); sand in the water table was more tan or gray-brown in color.

1.5 Hydrogeology

The MAB vicinity has both confined and unconfined aquifers. The Upper Noheji Formation holds a relatively shallow unconfined water table. The Middle Noheji acts as a leaky aquitard for confined aquifers within the Lower Noheji and Katti Formations. Groundwater recharge in the MAB area occurs either through streams and lakes to the north and west, or through the Pacific Ocean in the east, depending on local gradients.

No surface water is present at the JASDF compound or TF2. Much of TF2 is covered in grass, allowing groundwater infiltration, whereas the JASDF section is dominated by buildings, concrete and asphalt. Groundwater elevations decrease from 84.5 ft above mean sea level (MSL) near the western edge of the JASDF area to 72 ft above MSL at the eastern edge of TF2. In the JASDF area, groundwater flow is northeasterly, under a hydraulic gradient of 0.0025 ft/ft. The flow under TF2 turns easterly, towards the MAB border and the Pacific Ocean, with a gradient of 0.0044 ft/ft As these gradients are fairly flat, they are susceptible to minor direction variability, but the general gradient will remain easterly. The eastern border of TF2 is approximately 1350 to 1400 ft up-gradient from three Japanese drinking water wells.

1.6 Previous Investigations

In June 1996, approximately two inches of light non-aqueous phase liquid (LNAPL) was discovered in Tank Farm 2 Monitoring Well #3 (MW-3). The level of LNAPL in MW-3 has been increasing steadily and was measured at 24 inches in May, 1997. Laboratory interpretation of the chromatograms indicated multiple fuel sources at the site. Brewer Environmental Services (BES) identified potentially seven different fuel spill plumes. The different fuel types identified are gasoline, JP-4, JP-8 and diesel (BES, 1998).

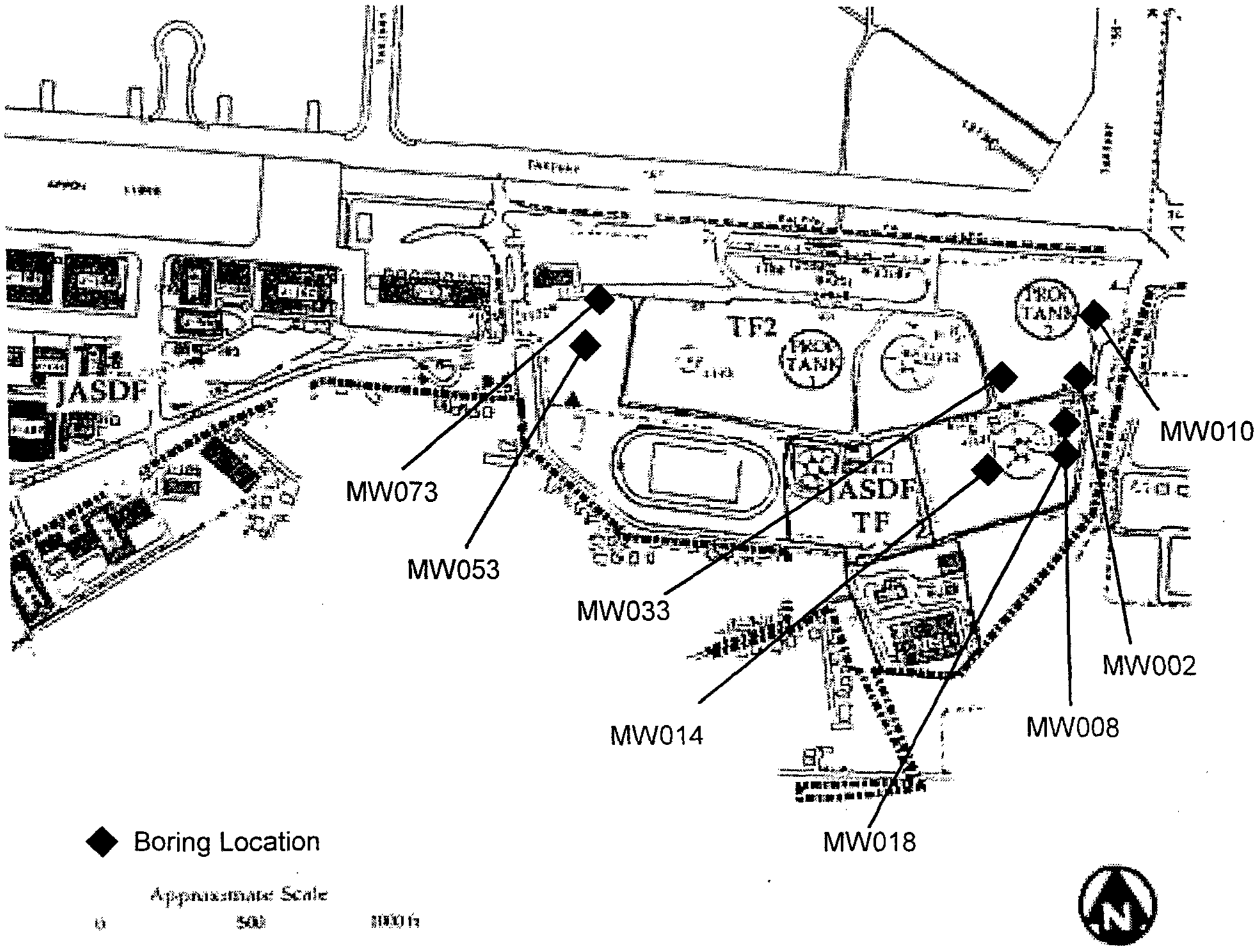
In October 1997, Brewer collected 100 soil samples at 10 ft depth intervals, until groundwater was encountered. The groundwater depth was between 22 and 32 ft bgs. An attempt was always made to collect the bottom sample slightly above the groundwater, in the capillary fringe zone. Results indicated widespread contamination from petroleum fuels throughout the TF2 area. Only six borings from the TF2 site exceeded the preliminary remediation goals for the site. All soil contamination detected above guidelines were found at the deepest sampling depths, between 20 and 30 ft bgs. Analytical results resembled both gasoline and JP-8. The highest gasoline and JP-8 values (at Location 10) were between 75 and 840 mg/kg, respectively (BES, 1998).

2.0 SAMPLING AND ANALYSIS

Unlike most demonstration efforts, the sampling plan and analytical approach were dictated by the concurrent efforts of AFCEE and EPA Kerr Laboratory. AFCEE personnel collected samples from nine borings at depths indicated by maximal readings from an *in-situ* infrared spectrometer. After quantification by the Kerr Laboratory, the residual soil from the samples were composited to provide three samples adequate in volume for analysis by the Direct Method. As a result of compositing soils from different locations, the hydrocarbon fractions detected may not be representative of TPH contamination at each of the sampling locations. Therefore, the results are suitable for demonstration purposes, but broader interpretations are limited.

2.1 Sample Collection

Figure 2-1 presents a map of the TF2 area and the locations where sampling borings were drilled for the AFCEE effort. Table 2-1 lists the borings sampled, depths of samples collected and which samples were composited for fractionation analysis. The original samples were collected from the borings and placed into 40 mL containers. These containers were sent to the Kerr Laboratory for analysis. Extra sample materials were shipped to Lancaster Laboratory, where they were composited and analyzed using the Direct Method. The Direct Method requires approximately 250 mL of soil for fractionation and moisture content analysis. Even after compositing the residuals, from the original nine (40 mL) samples, there was not a sufficient amount of soil to run both fractionation and moisture analyses on each composite sample. The Total Fluorescence Intensity values listed in Table 2-1 were extracted from their field notes and were used in addition to the proximity of sampling locations to determine which samples were composited together. Ideally, separate samples from various locations at a site are analyzed for fractions; and the variability of these fractions is examined to determine whether the degree of weathering across the site is similar or if areas can be identified where the hydrocarbon profiles differ considerably, In which case more focused sampling with direct method analysis might be warranted. Therefore, the samples listed in Table 2-1 that were combined, were assumed to be more similar, based on: 1) the relative expected contamination levels indicated by the fluorescence intensity readings and 2) their proximity or similar depth.



Adapted from BES, 1998

Figure 2-1 Tank Farm 2 Sample Locations

TABLE 2-1 SAMPLE INFORMATION

Soil Boring	Sample Depth	Composited Sample #	Laboratory Identification #	Total Fluorescence Intensity
MW010	26 ft	B1026	2993375	2
MW014	~20-30 ft	B1026	2993375	0
MW073	~20-30 ft	B1026	2993375	0
MW008	31 ft	B0831	2993376	120
MW018	29 ft	B0831	2993376	30
MW002	30 ft	B0831	2993376	90
MW033	20 ft	B3320	2993377	10
MW033	33 ft	B3320	2993377	90
MW053	29 ft	B3320	2993377	170

2.2 Analytical Methods

Due to the limited amount of sample matrix available, the soil samples were only analyzed by the Working Group Direct Method, developed by Shell Developmental Company. No attempt was made to assess moisture content or to quantify the TPH levels using conventional TPH methods. Direct Method analyses were performed by Lancaster Laboratories as part of the Hydrocarbon Speciation Project. (TPHCWG, 1998b)

2.3 Direct Method

The Direct Method determines values for TPH fractions within the EC6 to EC28 range (see Table 1-1). The sample is extracted and analyzed without concentration using a GC with a flame ionization detector (FID) to obtain a direct TPH measurement. This analysis can also be used to determine the nature of hydrocarbons present or to "fingerprint" the type or types of contamination. If samples are similar, a few may be chosen for further characterization by separation of aliphatic and aromatic fractions, which are then analyzed in a manner similar to the whole extract.

The separation of aliphatics and aromatics is done prior to the fractionation analysis. This separation procedure is either done using alumina (modified EPA Method 3611B) or silica gel (modified EPA Method 3630B or C), which can be used to fractionate petroleum materials into saturates, aromatics and polars. The Direct Method is similar to these methods except that a smaller column is used to minimize dilution and n-pentane is used for extraction and elution of aliphatics. Methylene chloride is used to elute aromatics from alumina and a mixture of methylene chloride and acetone is used for elution of aromatics from silica gel. The use of n-pentane instead of n-hexane allows for the determination of TPH starting at, and including, n-hexane (n-EC6).

Following separation of the aromatics and aliphatics on the alumina or silica gel column, fractionated extracts are analyzed by GC/FID. In cases where light-end constituents (i.e., < n-EC9) are observed, GC/mass spectrometry is performed, as for the quantitation of benzene, toluene, ethylbenzene and xylene (BTEX) using standard EPA Method 8020 or 8021A.

The Direct Method is not needed to analyze all soil samples collected at a petroleum contaminated site, but only enough samples necessary to identify the contaminants present at the site. In other words, once the petroleum fractions have been identified at a site, additional sampling, to characterize the extent of contamination, can rely on traditional, less expensive TPH analyses or *in-situ* methods rather than the Direct Method (that is if the TPH fingerprint is similar across the site). In addition, application of traditional EPA analytical methods is likely to be necessary to quantify the presence of indicator hydrocarbons such as carcinogenic polycyclic aromatic hydrocarbons (PAHs) or BTEX. Although this is optimum for a site, this approach could not be used due to: 1) compositing of samples from different locations and 2) too few samples, which were taken from an area of FT2 which is likely upgradient of contamination based on previous investigations.

2.4 Quality Control

Analytical methods were checked with a quality control analysis by pentane extraction of a spike to sample B1026. Results are included in Appendix A. Due to the limited number of samples available, normal quality control techniques for duplicates, trip blanks and temperature blanks were not possible on this demonstration.

3.0 WORKING GROUP TIER 1 RISK ASSESSMENT APPROACH

The first steps in a Tier 1 assessment are the identification of contaminant sources, transport mechanisms, exposure pathways and potential receptors based on existing site information. The approach used for calculating TPH RBSLs differs from that used in a typical ASTM RBCA (1995) analysis in that it incorporates the concepts of additivity of risks (for the TPH mixture), chemical saturation concentrations (C_{sat}) and residual saturation (RES). The application of these concepts in the calculation of RBSLs is discussed in detail in Appendix B. Treating TPH as a mixture is especially important for consideration of fate, transport and toxicological interactions between individual chemicals or fractions.

Noncarcinogenic risk for each fraction is represented by the hazard quotient (HQ), which is the ratio of the estimated daily intake of a contaminant in given media (e.g., soil) to a reference dose (RfD) as follows:

$$HQ_i = \frac{Intake\,Rate({}^{mg}/_{kg-day})}{RfD_i({}^{mg}/_{kg-day})}$$

The intake rate depends upon the frequency and duration of exposure, as well as the source concentration and the transport rates between the source and the receptor for cross media pathways. Additivity is incorporated into the calculation of a "whole TPH" hazard index (HI) and RBSL by apportioning the total risk (i.e., HI = 1 for the mixture) over the different fractions present. That is, rather than each fraction assuming risk equal to a HQ of 1, each fraction would be allotted a portion of the risk. The sum of the HQs from each fraction would be less than or equal to the HI of 1 for the mixture as depicted in the equation below:

$$HI = \sum_{i=1}^{i=n} HQ_i = \sum_{i=1}^{i=n} \frac{f_i C_{TPH}}{RBSL_i} \le 1$$

where:

HI = Hazard Index (typically ≤ 1) [unitless]

n = Number of fractions (13 total) [unitless]

HQ_i = Hazard Quotient for i^{th} specific fraction [unitless]

f_i = Percent Weight of i^{th} TPH fraction in whole TPH mixture [unitless]

C_{TPH} = TPH concentration in soil [mg/kg]

RBSL = Tier 1 risk-based screening level for a TPH fraction [mg/kg]

3.1 Physical Properties of the TPH Fractions

The 13 fractions in the Working Group approach were selected based on order of magnitude differences in partitioning properties. These properties are used in simple fate and transport models, provided in Appendix B, to evaluate the partitioning and migration of the TPH fractions for the different applicable pathways. This allows a more accurate estimation of exposure to the complex mixture than can be modeled from single TPH measurements.

Chemical properties, which specifically govern how a chemical interacts with its environment, include solubility vapor pressure, sorption coefficient and Henry's Law Constant. The physical properties of the 13 TPH fractions are provided in Table 3-1. The data and equations used to develop these fate and transport properties are available in the Working Group's Volume 3 (TPHCWG, 1998a).

TABLE 3-1 TPH FRACTIONS DERIVED FROM FATE AND TRANSPORT CHARACTERISTICS AND ASSOCIATED PROPERTIES[1]

	Solubility (mg/L)	Henry's Law Constant	Molecular Weight (g/mol)	Vapor Pressure (atm)	log K_{oc}[2] (cm^3/cm^3)	PF[3] (soil/water)	PF[3] (soil/vapor)
Aliphatics							
EC5-EC6	3.6E+01	3.4E+01	8.1E+02	3.5E-01	2.9E+00	1E+01	3E-01
>EC6-EC8	5.4E+00	5.1E+01	1.0+02	6.3E-02	3.6E+00	4E+01	9E-01
>EC8-EC10	4.3E-01	8.2E+01	1.3E+02	6.3E-03	4.5E+00	3E+02	6E+00
>EC10-EC12	3.4E-02	1.3E+02	1.6E+02	6.3E-04	5.4E+00	3E+03	5E+01
>EC12-EC16	7.6E-04	5.4E+02	2.0E+02	4.8E-05	6.7+E00	7E+04	1E+03
>EC16-EC35	1.3E-06	6.4E+03	2.7E+02	7.6E-06	9.0E+00	1E+07	1E+05
Aromatics							
EC6-EC7	1.8E+03	2.3E-01	7.8E+01	1.3E-01	1.9E+00	9E-01	4E+00
>EC7-EC8	5.2E+02	2.7E-01	9.2E+01	3.8E-02	2.4E+00	2E+00	9E+00
>EC8-EC10	6.5E+01	4.9E-01	1.2E+02	6.3E-03	3.2E+00	2E+01	5E+01
>EC10-EC12	2.5E+01	1.4E-01	1.3E+02	6.3E-04	3.4E+00	2E+01	2E+02
>EC12-EC16	5.8E+00	5.4E-02	1.5E+02	4.8E-05	3.7E+00	5E+01	2E+03
>EC16-EC21	5.1E-01	1.3E-02	1.9E+02	7.6E-06	4.2E+00	1E+02	4E+04
>EC21-EC35	6.6E-03	6.8E-04	2.4E+02	4.4E-09	5.1E+00	1E+03	3E+07

Notes: Table extracted in part from TPHCWG, 1998a.

[1] Based on an equivalent carbon number, which is proportional to normal boiling point.

[2] K_{oc} = organic carbon sorption coefficient

[3] PF – partition factors for soil to water and soil to vapor concentrations at equilibrium

Values based on pure compounds. Behavior may differ in complex mixtures.

3.2 Overview of Toxicity Criteria for Fate and Transport Fractions

The Working Group approach focuses on both carcinogenic and non-carcinogenic impacts to human health. In order to assess carcinogenic risk, indicator compounds are used (benzene and the carcinogenic PAHs). The assessment of non-carcinogenic risk uses the fraction-specific toxicity criteria summarized in Table 3-2. The majority of constituents in TPH are noncarcinogenic.

RfDs represent estimates of daily exposure to non carcinogenic compounds that are likely to be without appreciable risk of deleterious effects to the human population, including sensitive subgroups during a lifetime. One set of toxicity criteria may span different fate and transport fractions due to similar evaluated toxicity and also because of lack of toxicity findings. Yet, the fractions are assessed separately so that the exposure potential of each fraction may be estimated appropriately. In general, aromatic fractions have lower RfDs than aliphatic fractions and are approximately an order of magnitude more toxic than the corresponding aliphatic fraction. Exposure estimates are combined with RfDs for each fraction to estimate fraction-specific RBSLs. These fraction-specific RBSLs are then combined with a site-specific mixture composition to calculate a single mixture-specific TPH RBSL.

TABLE 3-2 WORKING GROUP TOXICOLOGY FRACTION-SPECIFIC RfDs

Effective Carbon Range	Aromatic RfD (mg/kg/day)	Critical Chronic Effect	Aliphatic RfD (mg/kg/day)	Critical Chronic Effect
EC5–EC6 EC7–EC8	0.20 – Oral 0.10 – Inhalation	Hepatotoxicity, Nephrotoxicity	5.0 - Oral 5.0 - Inhalation	Neurotoxicity
EC9–EC10 EC11–EC12 EC13–EC16	0.04 – Oral 0.05 – Inhalation	Decreased body weight	0.1 - Oral 0.3 - Inhalation	Hepatic and hematological changes
EC17–EC21 EC22–EC34	0.03 – Oral	Decreased body weight	1.0 - Oral	Hepatic granuloma (foreign body reaction)
>EC34	—	—	20 - Oral	Hepatic changes

If carcinogenic indicators are present, they must be evaluated separately since they often drive cleanup even in relatively low concentrations. The hazard assessment for TPH fractions would only be used in cases where indicator compounds are not present or are present below regulatory action levels. More information on the development of the RfDs is provided in the Working Group's Volume 4 (TPHCWG, 1998c).

4.0 ANALYTICAL RESULTS

The aromatic and aliphatic fraction results for the Field Demonstration soils generated using the Direct Method are provided in Table 4-1. The TPH concentrations detected ranged from approximately 700 to 12,000 mg/kg. However, as illustrated in Figure 4-1, the percent composition of hydrocarbon fractions from the three composited samples was fairly consistent.

TABLE 4-1 DIRECT METHOD ANALYTICAL RESULTS
(mg/kg wet weight)

Laboratory ID **Sample #** **TPH Fractions**	**2993375** **B1026** **(mg/kg)**	**2993376** **B0831** **(mg/kg)**	**2993377** **B3320** **(mg/kg)**
5-6 Aliphatics	167	289	<13
>6-8 Aliphatics	1069	2398	66
>8-10 Aliphatics	1025	2252	67
>10-12 Aliphatics	1610	2394	118
>12-16 Aliphatics	1093	1976	192
>16-21 Aliphatics	54.3	541	78
>21-35 Aliphatics	<83	112	<83
6-7 Aromatics (benzene)	<2	27	<0.3
7-8 Aromatics (toluene)	<2	109	0.5
>8-10 Aromatics	204	518	14
>10-12 Aromatics	364	608	26
>12-16 Aromatics	286	494	54.5
>16-21 Aromatics	<33	177	<33
>21-35 Aromatics	<83	<83	<83
Total Aliphatics	**5025**	**9961**	**551**
Total Aromatics	**912**	**1,978**	**<95**
Total Aliphatics + Aromatics	**5937**	**11,938**	**703**

Notes: 1. All values reported as wet weight concentrations due to insufficient samples for moisture determination.

2. Nondetects are indicated by a "<" followed by a limit of quantitation value.

3. Totals do not necessarily reflect the arithmetic sum of the detected fraction values because nondetects are not necessarily zeros and contribute to the area under the chromatogram curve yielding the total values.

Over 85% of the hydrocarbons reported were aliphatics, within the >EC6 to EC21 range. Highly branched aliphatics and cyclic alkanes, between >EC10 to EC16 consistently predominated, averaging approximately 44% of the "whole TPH". These compounds are generally resistant to biodegradation and compose the majority of most jet fuels. A considerable amount of lighter aliphatics was present. Aliphatics >EC6 to EC10 contributed an average of 32% of the petroleum mixture, suggesting that either little evaporative weathering has occurred or this material is from a relatively new release. Very low levels of aromatics were reported (primarily >EC10 to EC16).

Typically similar TPH profiles such as these across a site would indicate that an average of RBSLs developed would be applicable for the entire site. However, because the samples analyzed were composited from various locations and depth, one cannot make this assumption from these samples.

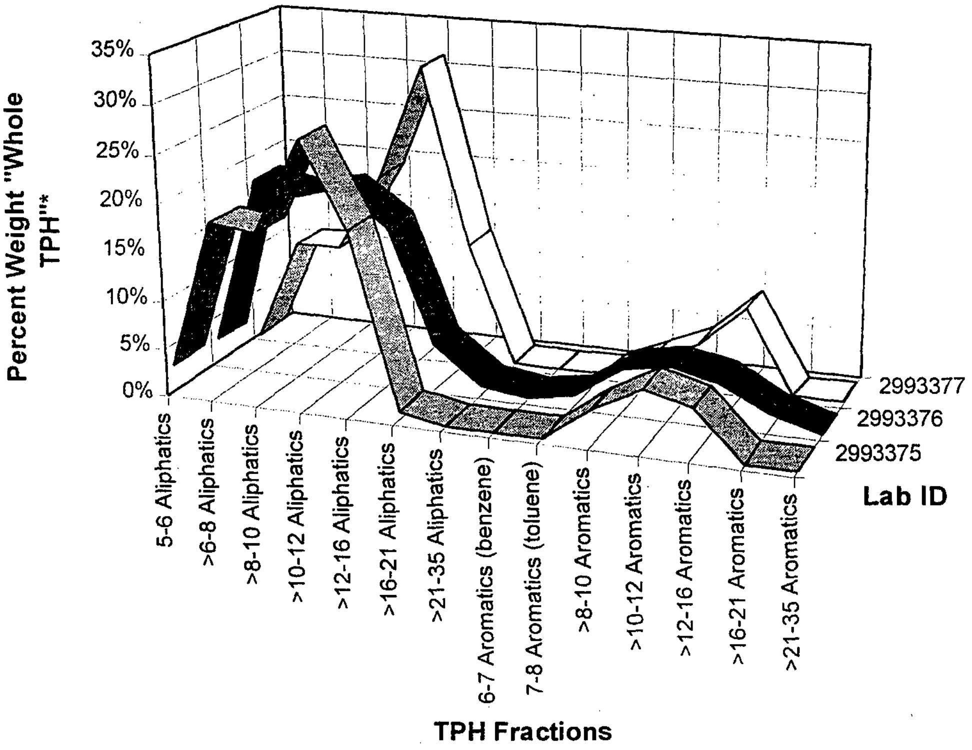


Figure 4-1 Fraction Composition: Direct Method*

***Note:** Percent Weight is based upon wet weight concentration

5.0 RISK ASSESSMENT RESULTS

For the purposes of the field demonstration, the RBCA analysis conducted using the Working Group approach was based upon a site conceptual model which assumes leaching from subsurface soil to groundwater and vapor transport to outdoor air. The area surrounding the impacted site, both on-base and off, is commercial and residential. The impacted area will remain industrial as part of the base for the foreseeable future; however, future land use may include residential.

Therefore, for a Tier 1 demonstration, RBSLs for both residential and commercial scenarios were developed. The pathways evaluated included soil contaminants leaching to groundwater used as a potable water source, volatilization from subsurface soil to outdoor air and direct contact with soil. The direct contact pathway is not complete because contamination was only noted in subsurface soil, but it was considered on the assumption that individuals could come into contact with impacted subsurface soils during construction. Volatilization to indoor air was not included in the assessment as buildings are not located on TF2 and therefore it does not represent a complete pathway. Exposure pathways evaluated include:

- Soil leaching to groundwater ; however it does not address existing groundwater contamination and its associated ingestion pathway..

- Volatilization from subsurface soils to outdoor air
- Direct contact with soils

A value of zero was used to represent nondetects in the calculation of the RBSLs. Often, half of the detection limit is assumed for nondetects. However, the use of zero is reasonable, given the fairly high levels of TPH reported and the low detection limits achieved. This is supported by: 1) BTEX analyses conducted separately from this effort, which resulted in little or no detects and 2) the fractions not detected were mainly aromatic >EC5 to EC7 (i.e., benzene and toluene). In addition, wet weight instead of dry weight concentrations were reported. Although, the overall percent weight of each fraction would not change between wet to dry weight concentration results (because the increase would be proportional in each fraction), moisture content does change detection limits. Therefore, without accurate information on moisture content, nondetects could not be incorporated into the RBSL calculations. The RBSL runs are provided in Appendix C.

Currently, the Working Group has not incorporated a protocol for the treatment of nondetects into their approach. This decision is left to the risk analyst. The use of half the detection limit for nondetects does not always result in lower RBSLs. For example, using half the detection limit can increase the RBSLs because the resulting risks are apportioned more equally among all fractions, including the heaviest fractions, which tend to be of lowest toxicity and mobility. Other demonstrations have shown, especially with jet fuels, that the weathered products often result in a lack of the lightest and the heaviest fractions, while highly mobile aliphatic >EC8 to EC12 components are predominant. Therefore, the use of zero for nondetects is reasonable and recommended in this demonstration.

5.1 Tier 1 Residential RBSLs

Residential RBSLs derived from the three composites are presented in Table 5-1. These RBSLs are examples of criteria that could be developed for residential land use within the base perimeters. And may be applicable off site as well if soil concentrations are similar. The soil leaching to groundwater pathway consistently resulted in the lowest RBSLs, averaging approximately 3000 mg/kg. Given that the analytical results reported a significant percentage of TPH in the lighter fractions, these RBSLs do not appear extremely low. This is because the light end fractions present were of the less water-soluble aliphatics. The highly soluble light end aromatics were not detected. As discussed earlier, this hydrocarbon profile may not represent other areas of TF2. For example, gasoline patterns have been identified from chromatograms of previous sampling investigations. Therefore, other samples may yield considerable light end aromatics. Depending on the TPH profiles, a separate set of RBSLs may be appropriate for other portions of the site.

Direct contact RBSLs were the next lowest criteria, averaging at 7700 mg/kg. There was much variability in the volatilization to outdoor air RBSLs due to the variability of the light end aliphatic fractions reported. Risks from this pathway are insignificant. Of the three composites analyzed, only Laboratory ID# 2993376 exceeds a HI of 1.0 for both the soil leaching and direct contact pathways.

TABLE 5-1 TIER 1 RESIDENTIAL SOIL RBSLs AND HIs

Laboratory ID	TPH	Soil Leaching		Volatilization to Outdoor Air		Direct Contact	
	(mg/kg)	(mg/kg)	HI	(mg/kg)	HI	(mg/kg)	HI
2993375	5937	3109	1.9	657971	0.0	7593	0.8
2993376	11938	2509	4.8	22141	0.5	7932	1.5
2993377	703	3649	0.2	610733	0.0	7588	0.1
Average	**6193**	**3089**	**2.3**	**430282**	**0.2**	**7704**	**0.8**

5.2 Tier 1 Commercial RBSLs

Example commercial RBSLs are presented in Table 5-2. Again, the soil leaching to groundwater RBSLs were consistently lowest, averaging approximately 10,000 mg/kg, among the three composite samples used The direct contact RBSLs were within the same range, averaging at 11,300 mg/kg. The risks from volatilization to outdoor air were insignificant.

TABLE 5-2 TIER 1 COMMERCIAL SOIL RBSLs AND HIs

Laboratory ID	TPH	Soil Leaching		Volatilization to Outdoor Air		Direct Contact	
	(mg/kg)	(mg/kg)	HI	(mg/kg)	HI	(mg/kg)	HI
2993375	5937	9368	0.6	2099426	0.0	11215	0.5
2993376	11938	7129	1.7	1049713	0.0	11716	1.0
2993377	703	13615	0.1	1294669	0.0	11208	0.1
Average	**6193**	**10038**	**0.8**	**1481269**	**0.0**	**11380**	**0.5**

5.3 Summary

The average residential RBSLs range from approximately 3,000 mg/kg for the soil leaching pathway to 430,000 mg/kg for the volatilization to outdoor air pathway. Typically, the most conservative RBSLs are selected as cleanup criteria. Due to the presence of residential surroundings of the site, the residential soil leaching RBSLs (3000 mg/kg) would likely be proposed and selected for cleanup criteria. Based on the soil analyzed for this study, this RBSL may be exceeded at certain locations of the TF2 site. One of the three composites used in this demonstration resulted in a HI greater than one for both the soil leaching and direct contact pathway. However, the average HI is less than one. These soil concentrations that exceed the screening values only indicate that there may be a potential for health impact over the duration of exposure assumed in the risk calculation. There is nothing in the calculation to indicate that these concentrations indicate a risk of immediate endangerment to life and health. It should be kept in mind, however that compositing samples can lead to either higher or lower concentrations than seen at isolated sampling locations. If the other soils at the site shared a similar TPH profile, the 3000 mg/kg RBSL would represent a criteria which would be protective of human health, based on viable soil exposure pathways. This means that a soil concentration of 3000 mg/kg of that approximate TPH profile would not lead to unacceptable risks to human from direct contact with soil, from soil vapors or from contaminants leaching from soil to groundwater. This does not address risk to human health from existing groundwater contamination.

6.0 UNCERTAINTIES

Several uncertainties exist in any risk assessment. The fate and transport models used to derive the leaching potential and volatilization potential of the contaminant through the soil are conservative which would tend to overestimate risk. The toxicity values used are also conservative but are based on currently accepted RfD and RfC calculations/paradigm.

The limited number samples obtained for this demonstration and the fact that they were composites is another source of uncertainty. From previous investigations, it appears that the nine boring locations are situated up gradient from the highest soil contamination on TF2. It is not possible to determine if the TPH profiles of the composites used are representative of the composition of TPH found at other locations of the site without more samples to analyze. In addition, during the compositing of the residual soil, volatiles may have been lost. If volatile aromatics and/or free product remains at the site, the potential for cross-media impacts and human health risks may be underestimated.

7.0 CONCLUSIONS AND RECOMMENDATIONS

The Working Group approach provides scientifically sound human health cleanup criteria for contaminated soils at the site, using US EPA accepted methods and criteria. Due to the multiple fuel types present at TF2, this approach could prove very beneficial because it identifies the hydrocarbon fractions present regardless of the fuel types released at the site. The composited samples, analyzed during this study, do indicate the presence of a wide range of hydrocarbon fractions. If the TPH profiles are similar at various locations across the site, the remainder of the site can be characterized using an inexpensive conventional TPH method and the RBSLs developed from the fractionation samples can be applied as criteria. This demonstration was very limited by sampling constraints.

From what limited data was evaluated in this demonstration the soil leaching to groundwater pathway is a potential risk to people living on site, given residential land use. If the Working Group approach were to be used at TF2, a more thorough assessment would require that:

1) More samples of adequate soil volume from areas of greater concentration should be analyzed using the Direct Method to identify possible variations in the TPH profiles.
2) The groundwater plume and the risk associated with it must be addressed, using other available modeling/assessment mechanisms.
3) A determination would be needed on whether U.S. EPA based criteria is appropriate for use at this location.
4) If carcinogenic BTEX and PAHs are present, they need to be assessed separately.
5) The absence of free petroleum product and the resultant contamination of ground water be demonstrated prior to using the Working Group method for assessing soil contamination.

8.0 REFERENCES

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TPHCWG. 1998b. A Risk-based Approach for the Management of Total Petroleum Hydrocarbons in Soil, Volume 1: Petroleum Hydrocarbon Analysis of Soil and Water in the Environment.

TPHCWG. 1998c. A Risk-based Approach for the Management of Total Petroleum Hydrocarbons in Soil, Volume 4: Development of Fraction Specific Reference Doses (RfDs) and Reference Concentrations (RfCs) for Total Petroleum Hydrocarbons (TPH).

APPENDIX A

ANALYTICAL DATA

HYDROCARBON SPECIATION PROJECT

C5 to C8 Hydrocarbons by Purge & Trap GC PID/FID

C8 to C35 Hydrocarbons by Pentane Extraction w/ Aliphatic/Aromatic Separation Performed on Silica Gel Column

"As Received (Wet Weight) Data"

Extractable Batch ID: 98255-0000A

Laboratory ID: 2993375
Sample ID: B1026

Approximate Carbon Number Range	TPH Pentane Extract (mg/kg)	LOQ	Aliphatic (mg/kg)	LOQ	Aromatic Hydrocarbons (mg/kg)	LOQ	Aliphatics + Aromatics (mg/kg)	Aliph + Arom Total (%)
VRH 1 *	NA	NA	100.4	40	ND	1	100.4	NA
VRH 2 **	NA	NA	641.3	40	ND	1	641.3	NA
>C8 - <=C10	815.3	8	614.9	8	122.1	8	737.0	90%
>C10 - <=C12	1341.4	8	966.2	8	218.3	8	1184.4	88%
>C12 - <=C16	962	20	655	20	172	20	827	86%
>C16 - <=C21	54	20	33	20	ND	20	52	96%
>C21 - <=C35	ND	50	ND	50	ND	50	ND	NA
Total >C8 - <=C35	3181	100	2274	100	547	100	2821	89%
Total >C5 - <=C35	NA	NA	3015	100	547	100	3562	NA

Laboratory ID: 2993375

*****C5 to C35 Hydrocarbons "Dry Weight Data"**

% moisture = 0.0

Sample ID: B1026

Approximate Carbon Number Range	TPH Pentane Extract (mg/kg)	LOQ	Aliphatic (mg/kg)	LOQ	Aromatic Hydrocarbons (mg/kg)	LOQ	Aliphatics + Aromatics (mg/kg)	Aliph + Arom Total (%)
VRH 1 *	NA	NA	100.4	40	ND	1	100.4	NA
VRH 2 **	NA	NA	641.3	40	ND	1	641.3	NA
>C8 - <=C10	815.3	8	614.9	8	122.1	8	737.0	90%
>C10 - <=C12	1341.4	8	966.2	8	218.3	8	1184.4	88%
>C12 - <=C16	962	20	655	20	172	20	827	86%
>C16 - <=C21	54	20	33	20	ND	20	52	96%
>C21 - <=C35	ND	50	ND	50	ND	50	ND	NA
Total >C8 - <=C35	3181	100	2274	100	547	100	2821	89%
Total >C5 - <=C35	NA	NA	3015	100	547	100	3562	NA

* Volatile Range Hydrocarbons (Range 1 Aliphatics = C5 to C6 aliphatic (total)hydrocarbons
Aromatics = C6 to C7 aromatic hydrocarbons (benzene only)

** Volatile Range Hydrocarbons (Range 2 Aliphatics = >C6 to C8 aliphatic hydrocarbons (total minus benzene and toluene)
Aromatics = >C7 to C8 aromatics (toluene only)

*****NOTE: Moisture determination not requested/performed. Dry weight calculation is not valid.**

HYDROCARBON SPECIATION PROJECT

Laboratory ID: 2993376

Extractable Batch ID: 98255-0000A

Sample ID: B0831

Approximate Carbon Number Range	TPH Pentane Extract (mg/kg)	LOQ	Aliphatic (mg/kg)	LOQ	Aromatic Hydrocarbons (mg/kg)	LOQ	Aliphatics + Aromatics (mg/kg)	Aliph + Arom Total (%)
VRH 1 *	NA	NA	173.2	40	16.06	1	189.3	NA
VRH 2 **	NA	NA	1438.6	40	65.67	1	1504.3	NA
>C8 - <=C10	1964.5	40	1351.2	8	310.6	8	1661.8	85%
>C10 - <=C12	1998.7	40	1436.2	8	364.5	8	1800.7	90%
>C12 - <=C16	1542	100	1185	20	296	20	1482	96%
>C16 - <=C21	473	100	325	20	106	20	431	91%
>C21 - <=C35	ND	250	67	50	ND	50	95	NA
Total >C8 - <=C35	6078	500	4364	100	1105	100	5469	90%
Total >C5 - <=C35	NA	NA	5976	100	1187	100	7163	NA

Laboratory ID: 2993376 *****C5 to C35 Hydrocarbons "Dry Weight Data"** % moisture = 0.0

Sample ID: B0831

Approximate Carbon Number Range	TPH Pentane Extract (mg/kg)	LOQ	Aliphatic (mg/kg)	LOQ	Aromatic Hydrocarbons (mg/kg)	LOQ	Aliphatics + Aromatics (mg/kg)	Aliph + Arom Total (%)
VRH 1 *	NA	NA	173.2	40	16.06	1	189.3	NA
VRH 2 **	NA	NA	1438.6	40	65.67	1	1504.3	NA
>C8 - <=C10	1964.5	40	1351.2	8	310.6	8	1661.8	85%
>C10 - <=C12	1998.7	40	1436.2	8	364.5	8	1800.7	90%
>C12 - <=C16	1542	100	1185	20	296	20	1482	96%
>C16 - <=C21	473	100	325	20	106	20	431	91%
>C21 - <=C35	ND	250	67	50	ND	50	95	NA
Total >C8 - <=C35	6078	500	4364	100	1105	100	5469	90%
Total >C5 - <=C35	NA	NA	5976	100	1187	100	7163	NA

* Volatile Range Hydrocarbons (Range 1 Aliphatics = C5 to C6 aliphatic (total)hydrocarbons
Aromatics = C6 to C7 aromatic hydrocarbons (benzene only)

** Volatile Range Hydrocarbons (Range 2 Aliphatics = >C6 to C8 aliphatic hydrocarbons (total minus benzene and toluene)
Aromatics = >C7 to C8 aromatics (toluene only)

*****NOTE: Moisture determination not requested/performed. Dry weight calculation is not valid.**

HYDROCARBON SPECIATION PROJECT

C5 to C8 Hydrocarbons by Purge & Trap GC PID/FID
C8 to C35 Hydrocarbons by Pentane Extraction w/ Aliphatic/Aromatic Separation Performed on Silica Gel Column
"As Received (Wet Weight) Data"

Extractable Batch ID: 98255-0000A

Laboratory ID: 2993377
Sample ID: B3320

Approximate Carbon Number Range	TPH Pentane Extract (mg/kg)	LOQ	Aliphatic (mg/kg)	LOQ	Aromatic Hydrocarbons (mg/kg)	LOQ	Aliphatics + Aromatics (mg/kg)	Aliph + Arom Total (%)
VRH 1 *	NA	NA	ND	8	ND	0.2	ND	NA
VRH 2 **	NA	NA	39.7	8	0.317	0.2	40.0	NA
>C8 - <=C10	57.7	8	40.3	8	8.4	8	48.7	84%
>C10 - <=C12	105.0	8	70.5	8	15.9	8	86.4	82%
>C12 - <=C16	173	20	115	20	33	20	148	86%
>C16 - <=C21	74	20	47	20	ND	20	66	88%
>C21 - <=C35	ND	50	ND	50	ND	50	ND	NA
Total >C8 - <=C35	421	100	286	100	ND	100	377	90%
Total >C5 - <=C35	NA	NA	330	100	ND	100	422	NA

Laboratory ID: 2993377
Sample ID: B3320

*****C5 to C35 Hydrocarbons "Dry Weight Data"**

% moisture = 0.0

Approximate Carbon Number Range	TPH Pentane Extract (mg/kg)	LOQ	Aliphatic (mg/kg)	LOQ	Aromatic Hydrocarbons (mg/kg)	LOQ	Aliphatics + Aromatics (mg/kg)	Aliph + Arom Total (%)
VRH 1 *	NA	NA	ND	8	ND	0.2	ND	NA
VRH 2 **	NA	NA	39.7	8	0.317	0.2	40.0	NA
>C8 - <=C10	57.7	8	40.3	8	8.4	8	48.7	84%
>C10 - <=C12	105.0	8	70.5	8	15.9	8	86.4	82%
>C12 - <=C16	173	20	115	20	33	20	148	86%
>C16 - <=C21	74	20	47	20	ND	20	66	88%
>C21 - <=C35	ND	50	ND	50	ND	50	ND	NA
Total >C8 - <=C35	421	100	286	100	ND	100	377	90%
Total >C5 - <=C35	NA	NA	330	100	ND	100	422	NA

* Volatile Range Hydrocarbons (Range 1 Aliphatics = C5 to C6 aliphatic (total)hydrocarbons
Aromatics = C6 to C7 aromatic hydrocarbons (benzene only)

** Volatile Range Hydrocarbons (Range 2 Aliphatics = >C6 to C8 aliphatic hydrocarbons (total minus benzene and toluene)
Aromatics = >C7 to C8 aromatics (toluene only)

*****NOTE: Moisture determination not requested/performed. Dry weight calculation is not valid.**

Prepared by Delwyn K Schumacher

9/23/98

HYDROCARBON SPECIATION PROJECT

Quality Control Analyses (MS) for Hydrocarbon Speciation
C8 to C35 Hydrocarbons by Pentane Extraction "As Received (Wet Weight) Data"

Laboratory ID: 2993375
Sample ID: B1026

Batch ID: 98255-0000A

Specific Aliphatic Compounds in Aliphatic Fraction

Analyte	Approximate Carbon Number Range	Background (mg/kg)	LOQ	MS (mg/kg)	MS Result (mg/kg)	Recovery (%)
n-Octane	C8	78.6	1	20.0	93.2	73.4%
n-Decane	>C8 - <=C10	91.7	1	20.0	106.0	71.5%
n-Dodecane	>C10 - <=C12	78.7	1	20.0	95.9	85.7%
n-Hexadecane	>C12 - <=C16	1.1	1	20.0	21.6	102.5%
n-Eicosane	>C16 - <=C21	ND	1	20.0	20.3	101.5%
n-Docosane	>C21 - <=C35	ND	1	20.0	20.0	100.2%
n-Dotriacontane	>C21 - <=C35	ND	1	20.0	19.6	98.0%

Specific Aromatic Compounds in Aromatic Fraction

Analyte	Approximate Carbon Number Range	Background (mg/kg)	LOQ	MS (mg/kg)	MS Result (mg/kg)	Recovery (%)
Ethylbenzene	>C8 - <=C10	14.0	1	20.0	27.5	67.8%
1,3,5,-Trimethylbenzene	>C8 - <=C10	7.2	1	20.1	23.9	83.3%
Naphthalene	>C10 - <=C12	9.4	1	20.0	26.2	84.0%
Acenaphthalene	>C12 - <=C16	ND	1	20.0	19.0	94.8%
Anthracene	>C16 - <=C21	ND	1	20.0	18.5	92.4%
Chrysene	>C21 - <=C35	ND	1	20.0	17.7	88.6%

HYDROCARBON SPECIATION PROJECT

Quality Control Analyses (Blank/LCS/LCSD) for Hydrocarbon Speciation
C8 to C35 Hydrocarbons by Pentane Extraction

Batch ID: 98255-0000A

Aliphatic Fraction

Approximate Carbon Number Range	Blank (mg/kg)	LOQ (mg/kg)	Amount Spiked (mg/kg)	LCS Result (mg/kg)	% LCS Recovery	LCSD Result (mg/kg)	% LCSD Recovery	RPD (%)
>C8 - <=C10	0.1	4	20.0	22.3	110.8%	22.5	112.0%	1.0%
>C10 - <=C12	0.0	8	20.0	20.5	102.3%	21.9	109.6%	6.9%
>C12 - <=C16	0.2	20	20.0	21.8	108.1%	22.8	113.1%	4.4%
>C16 - <=C21	2.1	20	20.0	24.6	112.2%	27.0	124.3%	9.4%
>C21 - <=C35	3.6	50	40.0	46.4	107.2%	55.0	128.7%	17.0%
Total	6.0	100	120	136	108.0%	149.3	119.4%	9.6%

Specific Aliphatic Compounds in Aliphatic Fraction

Analyte	Blank (mg/kg)	LOQ (mg/kg)	Amount Spiked (mg/kg)	LCS Result (mg/kg)	% LCS Recovery	LCSD Result (mg/kg)	% LCSD Recovery	RPD (%)
n-Octane	ND	1	20.0	20.3	101.6%	22.0	109.8%	7.7%
n-Decane	ND	1	20.0	21.1	105.4%	22.5	112.6%	6.6%
n-Dodecane	ND	1	20.0	21.1	105.7%	22.4	112.2%	6.0%
n-Hexadecane	ND	1	20.0	21.4	106.9%	22.2	111.2%	4.0%
n-Eicosane	ND	1	20.0	20.8	104.1%	21.5	107.6%	3.3%
n-Docosane	ND	1	20.0	20.7	103.5%	21.5	107.5%	3.7%
n-Dotriacontane	ND	1	20.0	20.3	101.7%	21.1	105.7%	3.8%

Aromatic Fraction

Approximate Carbon Number Range	Blank (mg/kg)	LOQ (mg/kg)	Amount Spiked (mg/kg)	LCS Result (mg/kg)	% LCS Recovery	LCSD Result (mg/kg)	% LCSD Recovery	RPD (%)
>C8 - <=C10	0.3	8	40.1	36.8	91.1%	42.8	106.0%	14.9%
>C10 - <=C12	0.3	8	20.0	21.3	105.2%	23.8	117.3%	10.7%
>C12 - <=C16	1.0	20	20.0	21.7	103.8%	25.3	121.8%	15.3%
>C16 - <=C21	5.7	20	20.0	24.0	91.2%	28.5	113.6%	17.1%
>C21 - <=C35	23.4	50	20.0	35.2	59.1%	39.5	80.5%	11.4%
Total	30.7	100	120	139.1	90.3%	159.8	107.5%	13.8%

Specific Aromatic Compounds in Aromatic Fraction

Analyte	Blank (mg/kg)	LOQ (mg/kg)	Amount Spiked (mg/kg)	LCS Result (mg/kg)	% LCS Recovery	LCSD Result (mg/kg)	% LCSD Recovery	RPD (%)
Ethylbenzene	ND	1	20.0	17.5	87.4%	20.8	104.2%	17.5%
1,3,5,-Trimethylbenzene	ND	1	20.1	19.9	99.3%	22.6	112.7%	12.6%
Naphthalene	ND	1	20.0	20.2	101.1%	22.6	112.9%	11.1%
Acenaphthalene	ND	1	20.0	20.2	101.2%	22.6	113.2%	11.1%
Anthracene	ND	1	20.0	19.9	99.7%	22.6	113.1%	12.5%
Chrysene	ND	1	20.0	19.8	99.1%	22.1	110.7%	11.0%

APPENDIX B

RBSL CALCULATIONS

APPENDIX B RBSL CALCULATIONS

The procedure for calculating a TPH RBSL for cross-media pathways based upon summing the risk from each fraction is complex. Please note that the following procedure is only appropriate for calculation of RBSLs for cross-media pathways since it sets as an upper limit for the RBSL the degree of saturation, which does not limit exposure for direct routes such as soil ingestion, dermal exposure, and inhalation of particulates. An additional procedure used to calculate exposure for direct pathways is provided later.

Cross-media Pathways

Partitioning qualities govern how a chemical interacts with its environment. Specific physical properties responsible include solubility, vapor pressure, sorption coefficient and Henry's Law Constant. A brief discussion of the role these parameters play in basic partitioning in the environment is provided in the following paragraphs. The fraction-specific values for each of the described fate and transport parameters is provided in Table 3-1. The equations used to develop these fate and transport properties is available in the TPH Criteria Working Group "Volume III. Selection of Representative TPH Fractions Based on Fate and Transport Considerations" (1998).

The solubility of aromatic hydrocarbons, for any EC number, is generally greater than that of aliphatic hydrocarbons, especially at high EC values. The variability in solubility around any given EC value is about an order of magnitude. The higher solubility of the aromatics means that aromatic hydrocarbons are more likely to be present as dissolved constituents in groundwater than are the corresponding aliphatic hydrocarbons.

The soil-water sorption coefficient (k_s) expresses the tendency of a chemical to be adsorbed onto a soil particle. The magnitude of the sorption coefficient for most soil/water systems is a function of the hydrophobicity of the chemical (as indicated by its solubility) and the organic carbon content of the soil. For non-ionic, hydrophobic chemicals such as petroleum hydrocarbons, the primary property found to control sorption is the organic carbon content (f_{oc}) of the soil.

In general, aliphatic fractions are more likely to remain bound to a soil particle than the aromatic fraction of an equivalent EC. This tendency was previously indicated by the low solubility observed for aliphatic fractions. The majority of log k_{oc} (carbon-water sorption coefficient) values presented in Table 3-1 were derived from the octanol-water partitioning coefficient.

There is very little difference in vapor pressure between aliphatic and aromatic constituents of an equivalent EC. In effect, the EC and vapor pressure are closely related. This relationship is expected because both EC and vapor pressure are largely functions of a compound's boiling point.

The Henry's law constant (H_c) is definable as an air-water partitioning coefficient and may be measured as the ratio of a compound's concentration in air to its concentration in water at equilibrium. Aliphatics and aromatics behave differently based on Henry's law constant. For aromatic fractions, the Henry's law constant decreases with increasing EC; for aliphatic fractions, the Henry's law constant is virtually unaffected by EC. In general, aliphatic hydrocarbons are less soluble and more volatile than aromatic hydrocarbons. It is important to note, however, that benzene, an aromatic compound, is very volatile and more toxic than the corresponding aliphatic fractions. Therefore, when present, benzene is likely to drive risk calculations for pathways involving volatilization from soil or groundwater.

The parameters described above are combined into simple fate and transport models to evaluate the partitioning and migration of chemicals for the different applicable pathways. For leaching and volatilization pathways where transport and therefore exposure are maximized at the saturation concentration for specific fractions, the following equation is solved:

$$HI = \sum_{i=1}^{i=n} HQ_i = Min\left(\sum_{i=1}^{i=n} \frac{f_i C_{TPH}}{RBSL_i}, \sum_{i=1}^{i=n} \frac{C_{i sat}}{RBSL_i}\right) \leq 1 \quad \text{given that,}$$

$$\sum_{i=1}^{i=13} f_i = \sum_{i=1}^{i=n} \frac{C_i}{C_{TPH}} = 1$$

where,

HI = Hazard Index (typically ≤ 1) [unitless]

n = number of fractions (13 total) [unitless]

HQ = Hazard Quotient for each specific fraction [unitless]

f = Percent Weight of each TPH fraction in total TPH mixture [unitless]

$C_{i\,sat}$ = Saturation concentration for i^{th} TPH fraction (mg/kg)

$RBSL_i$ = Tier 1 risk-based screening level for i^{th} TPH fraction (mg/kg)

C_{TPH} = Concentration of TPH mixture

The saturation concentration is defined by the following equation:

$$C_{sat}\left[{}^{mg}/_{kg}\right] = \frac{S}{\rho_s} * [H_c\theta_{as} + \theta_{ws} + k_s\rho_s]$$

where:

S = Fraction effective solubility [mg/L]

ρ_s = Soil Bulk Density [g/cm^3]

H_c = Henry's Constant [atm-m^3/mol]

θ_{as} = Volumetric air content of the soil [cm^3/cm^3]

θ_{ws} = Volumetric water content of the soil [cm^3/cm^3]

k_s = Soil sorption coefficient (k_{oc}*f_{oc}) [cm^3/g]

Note: The effective solubility of a hydrocarbon fraction is equal to the fraction's solubility limit multiplied by the mole fraction of the hydrocarbon fraction in the mixture (i.e., TPH).

The value obtained for C_{sat} will vary considerably if the effective C_{sat} of each fraction present in the sample is considered through the use of Raoult's law. The two equations above are iteratively solved for each TPH fraction, which is the additive mixture RBSL for the soil sample.

Residual saturation is the point at which any increase in chemical concentration will not change the risk, up until the point at which free product migration becomes an issue. For purposes of comparing RBSLs obtained using different analytical fractionation methods, such as the MADEP TPH Method, Raoult's law was not used to calculate the RBSLs presented in the following sections.

Soil Leaching to Groundwater Pathway

Leaching of contaminants from impacted soil into groundwater through infiltrating water is one exposure pathway evaluated in the RBCA analysis. Soil RBSLs are calculated to be protective of groundwater quality. This involves: 1) calculating a groundwater RBSL ($RBSL_{gw}$) to determine an acceptable water concentration, 2) calculating a leachate concentration protective of groundwater (based on the groundwater RBSL), and 3) calculating a soil concentration which would result in this leachate concentration. The following equation calculates the $RBSL_{gw}$ for ingestion.

$$RBSL_{gw}\left[\frac{mg}{L-water}\right] = \frac{THQ \times RfD_o \times BW \times AT_n \times 365\,{}^{days}\!/_{yr}}{IR_{water} \times EF \times ED}$$

where:
THQ = Target hazard quotient [unitless]
RfD_o = Oral chronic reference dose [mg/kg-day]
BW = Body weight [kg]
AT_n = Averaging time for noncarcinogens [yrs]
IR_{water} = Daily ingestion rate [L/day]
EF = Exposure frequency [days/yr]
ED = Exposure Duration [yrs]

The $RBSL_{gw}$ is based on a target hazard quotient of 1.0. Exposure parameters are provided in Table B-1. RfDs for the fractions are listed in Table 3-2.

TABLE B-1 TIER 1 DEFAULT EXPOSURE FACTORS

Name	Parameter	Units	Residential Scenario	Commercial Scenario
Averaging Time: carcinogens	At_c	y	70	70
Averaging Time: non-carcinogens	At_n	y	30	25
Body Weight	BW	kg	70	70
Exposure Duration	ED	y	30	25
Exposure Frequency	EF	days/y	350	250
Ingestion rate: soil	IR_{soil}	mg/day	100	50
Inhalation Rate: air-indoor	IR_{air-in}	m^3/day	20	20
Inhalation Rate: air-outdoor	$IR_{air-out}$	m^3/day	20	20
Ingestion rate: water	IR_w	L/day	2	1
Soil Adherence Factor	M	mg/cm^2	0.5	0.5
Dermal Absorption Factor	RAF_d	-	c.s.	c.s.
Oral Absorption Factor	RAF_o	-	1	1
Skin surface area	SA	cm^2/day	3160	3160
Target Hazard Quotient for Individual Constituents.	THQ	-	1	1
Target Excess Ind. Lifetime Cancer Risk	TR	-	1E-06	1E-06

The analytical model used to estimate soil leaching to groundwater determines the partitioning of a constituent into water, vapor and sorbed phases based on the physical and chemical properties of the constituent. In this model, infiltrating water migrates through contaminated soils in the vadose zone. At this point, some of the contaminant partitions from the soil or vapor phase into the water phase. This leachate is then assumed to migrate completely and instantaneously into groundwater. Some dilution of the leachate is included using an attenuation factor based on infiltration rate, groundwater velocity, source width and height of the mixing zone in the water column. The equation describing this attenuation factor (AF) is as follows:

$$AF = \left[1 + \frac{U_{GW}\delta_{GW}}{IW}\right]$$

where:

U_{GW} = Groundwater velocity [ft/day]

δ_{GW} = Height of groundwater mixing zone [ft]

I = Precipitation infiltration rate [ft/day]

W = Width of the source area parallel to the mixing zone [ft]

Partitioning into the three phases, soil, water and air, is governed by the partitioning factor. As Henry's law constant is applicable only to dilute solutions, the use of this model is not appropriate when free phase liquid is present. The partitioning factor (PF) is shown below:

$$PF = \frac{[\theta_{ws} + k_s\rho_s + H_c\theta_{as}]}{\rho_s}$$

where,

θ_{ws} = Soil volumetric water content [cm^3/cm^3]
k_s = Soil sorption coefficient (k_{oc}*f_{oc}) [cm^3/g]
ρ_s = Soil density [g/cm^3]
H_c = Henry's Constant [atm-m^3/mol]
θ_{as} = Soil volumetric air content [cm^3/cm^3]

The PF multiplied by AF, which accounts for dilution of leached water into underlying groundwater, is termed the leaching factor (LF). The ultra-conservative leaching model assumes that no attenuation of leachate occurs from the vadose to the saturated zone. In fact, biological degradation of the constituent or repartitioning onto soil or into the vapor phase are all likely to occur as the leachate migrates to groundwater. Other assumptions of the model include: 1) a constant chemical concentration in the subsurface soils, 2) linear equilibrium partitioning within the soil matrix between sorbed, dissolved and vapor phases, 3) steady-state leaching from the vadose zone to groundwater, and 4) steady state, well-mixed dispersion of the leachate within the groundwater mixing zone. Therefore the LF, which governs the movement of contaminants from soil to infiltrating water, incorporates both the PF and the AF, in the following equation:

$$LF = \frac{\rho_s}{[\theta_{ws} + k_s + H\theta_{as}]\left(1 + \frac{U_{gw}\delta_{gw}}{IW}\right)}$$

where:

LF = leaching factor [mg/L-H_2O / mg/kg-soil]
U_{gw} = groundwater Darcy velocity [cm/yr]
δ_{gw} = groundwater mixing zone thickness [cm]
I = infiltration rate of water through soil [cm/yr]
W = width of source area parallel to groundwater flow direction [cm]

Parameters for the leaching pathway are provided in Table B-2. Once the LF has been established, fraction-specific soil RBSLs may be calculated as follows:

$$RBSL_s\left[\frac{mg}{kg-soil}\right] = \frac{RBSL_w\left[\frac{mg}{L-air}\right]}{LF_{sw}}$$

The fraction-specific RBSLs are then used to calculate "whole TPH" RBSLs.

Volatilization to Indoor Air Pathway

The mathematical model used to estimate volatilization from soil to indoor air is based upon the partitioning of a constituent into water, vapor and sorbed phases as determined by the physical properties of the chemical. The model accounts for the contaminant partitioning into soil pore gas and migrating through the vadose zone to the base of a building foundation. From there the gas diffuses through cracks in the foundation and into the building air space, where exposure through inhalation may occur.

The first step in calculating a soil RBSL for the indoor air pathway requires the calculation of an air concentration or RBSL, which is protective of indoor air quality (based on a target HQ of 1.0). Indoor air RBSLs are calculated for each TPH fraction and then a whole TPH RBSL is calculated based on the percent composition of each fraction. The following equation is used to calculate the air RBSLs:

$$RBSL_{air}\left[\frac{\mu g}{m^3 air}\right]=\frac{THQ\times RfD_i\times BW\times AT_n\times 365\,{}^{days}\!/\!{}_{yr}\times 10^3\,{}^{\mu g}\!/\!{}_{mg}}{IF_{air-in}\times EF\times ED}$$

where:

THQ = Target hazard quotient [unitless]
RfD_i = Inhalation chronic reference dose [mg/kg-day]
BW = Body weight [kg]
AT_n = Averaging time for noncarcinogens [yrs]
IF_{air-in} = Daily inhalation rate [m^3/day]
EF = Exposure frequency [days/yr]
ED = Exposure Duration [years]

The second step in calculating a soil concentration ($RBSL_{soil}$) which will result in an acceptable indoor air concentration ($RBSL_{air}$) is to model the transport of contaminants from the vadose soil to indoor air. This model is extremely conservative, assuming: 1) a constant chemical concentration in subsurface soils; 2) linear equilibrium partitioning in the soil between sorbed, dissolved and vapor phases; and 3) steady-state vapor- and liquid-phase diffusion through the vadose zone and foundation cracks. In addition, the model assumes that vapors migrate completely and instantaneously into the building, i.e., no attentuation occurs. It does not account for any biodegradation and soil sorption which could occur as the vapor migrates through the vadose zone.

Dilution of vapor is expected to occur between the source and the building. Therefore the following diffusion factor is used:

$$D_s^{eff}\left[\frac{cm^2}{s}\right]=D^{air}\frac{\theta_{as}^{3.33}}{\theta_T^2}+D^{wat}\frac{1}{H_c}\times\frac{\theta_{ws}^{3.33}}{\theta_T^2}$$

where:

D^{air} = Diffusion coefficient in air [cm^2/sec]
θ_{as} = Soil volumetric air content [cm^3-air/cm^3-soil]
θ_T = Total soil porosity [cm^3/cm^3]
D^{wat} = Diffusion coefficient in water [cm^2/sec]
H_c = Henry's constant [cm^3-air/cm^3-soil]
θ_{ws} = Soil volumetric water content [cm^3-water/cm^3-soil]

TABLE B-2 PARAMETERS FOR CROSS-MEDIA RBSL CALCULATIONS

Description	Parameter	Units	Tier 1 Default Values
Ambient air mixing zone height	δ_{air}	cm	200
Areal fraction of cracks in foundations/walls	η	cm^2/cm^2	0.01
Averaging time for vapor flux	τ	s	7.88E+8
Carbon-water sorption coefficient	k_{oc}	cm^3/g	c.s.
Depth to groundwater (hcap+hv)	L_{GW}	cm	300
Depth to subsurface soil sources	L_S	cm	61
Diffusion coefficient in air	D^{air}	cm^2/s	c.s.
Diffusion coefficient in water	D^{wat}	cm^2/s	c.s.
Enclosed space air exchange rate	ER	1/s	0.00023
Enclosed space foundation or wall thickness	L_{crack}	cm	15
Enclosed space volume/infiltration area ratio	L_B	cm	300.
Fraction organic carbon in soil	f_{oc}	g/g	0.01
Groundwater Darcy velocity	μ_{gw}	cm/yr	2500
Groundwater mixing zone thickness	δ_{gw}	cm	200
Henry's Law Constant	H	(cm^3/cm^3)	c.s.
Infiltration rate of water through soil	I	cm/yr	30
Lower depth of surficial soil zone	d	cm	100
Particulate emission rate	PE	g/cm^2-s	2.2E-10
Particulate Emission Rate	VF_p	$(mg/m^3)/$ (mg/kg)	6.90E-14
Pure component solubility in water	S	mg/L	c.s.
Soil bulk density	ρ	g/cm^3	1.7
Soil-water sorption coefficient	k_s	cm^3/g	Foc*koc
Thickness of capillary fringe	h_{cap}	cm	5
Thickness of vadose zone	h_v	cm	295
Total soil porosity	θ_T	cm^3/cm^3	0.38
Volatilization Factor	VF_i	$\frac{(mg/m^3)}{(mg/m^3)}$	c.s. & m.s.
Volumetic air content in vadose zone soils	θ_{as}	cm^3/cm^3	0.03
Volumetric air content in capillary fringe soils	θ_{acap}	cm^3/cm^3	0.038
Volumetric air content in foundation cracks	θ_{acrack}	cm^3/cm^3	0.26
Volumetric water content vadose zone soils	θ_{ws}	cm^3/cm^3	0.12
Volumetric water content: capillary fringe	θ_{wcap}	cm^3/cm^3	0.342
Volumetric water content: foundation cracks	θ_{wcrack}	cm^3/cm^3	0.12
Width of source area parallel to flow direction	W	cm	1500
Wind speed above ground surface	U_{air}	cm/s	225

c.s. = chemical specific
m.s. = media specific

The diffusion of the pore gas through cracks in the foundation is governed by the following equation:

$$D^{eff}_{crack}\left[\frac{cm^2}{s}\right] = D^{air}\frac{\theta^{3.33}_{acrack}}{\theta^2_T} + D^{wat}\frac{1}{H_c}\times\frac{\theta^{3.33}_{wcrack}}{\theta^2_T}$$

where:
D^{air} = Diffusion coefficient in air [cm^2/sec]
θ_{acrack} = Volumetric air content in foundation [cm^3-air/cm^3]
θ_T = Total soil porosity [cm^3/cm^3]
D^{wat} = Diffusion coefficient in water [cm^2/sec]
H_c = Henry's constant [cm^3-air/cm^3-soil]
θ_{wcrack} = Volumetric water content in foundation [cm^3-water/cm^3]

The default parameters used in these equations are provided in Table B-2.

Chemical Partitioning

The partitioning equation which accounts for the movement of chemicals from the soil into the vapor phase in the soil pore space is defined as the partitioning factor (soil/vapor phase) as follows:

$$PF_{S-V} = \frac{H_c\rho_s}{\theta_{ws}+k_s\rho_s+H_c\theta_{as}}$$

where:
PF_{S-V} = Soil/Vapor phase partitioning factor (unitless)
H_c = Henry's Constant [cm^3-water/cm^3-air]
ρ_s = Soil bulk density [g/cm^3]
θ_{ws} = Soil volumetric water content [cm^3/cm^3]
k_s = Soil sorption coefficient (k_{oc}*f_{oc}) [cm^3/g]
θ_{as} = Soil volumetric air content [cm^3/cm^3]

The diffusion coefficients and partitioning factor are combined to yield a subsurface soil to enclosed space volatilization factor (VF_{sesp}), which takes into account partitioning, diffusion in the vadose zone, effective diffusion into an enclosed space and adds terms for accumulation of vapors in the enclosed space. The VF is calculated as follows:

$$VF_{sesp} = \frac{\dfrac{(PF_{S-V})D^{eff}_s}{L_s(ER)L_B}}{1+\dfrac{D^{eff}_s}{ER\,L_s}+\dfrac{D^{eff}_s+L_{crack}}{(L_sD^{eff}_{crack})\times\eta}}\times 10^3\left[\frac{cm^3-kg}{m^3-g}\right]$$

where:
PF_{s-v} = Soil/Vapor phase partitioning factor (unitless - see equation above)
D^{eff}_s = Effective diffusion coefficient in soil [cm^2/s]
L_s = Depth to subsurface soil sources [cm]

ER = Enclosed-space air exchange rate [s^{-1}]
L_B = Enclosed-space volume/infiltration area ratio [cm]
D^{eff}_{crack} = Effective diffusion coefficient through foundation cracks [cm^2/s]
L_{crack} = Enclosed-space foundation or wall thickness [cm]
η = Areal fraction of cracks in foundation/walls [cm^2/cm^2]

Values in these calculations are provided in Table B-2. The term VF_{sesp}, when combined with the allowable concentration of contaminant in the air space ($RBSL_{air}$), determines the maximum allowable concentration in the subsurface soil source area as shown in the following equation:

$$RBSL_{svin}\left[\frac{mg}{kg-soil}\right]=\frac{RBSL_{air}\left[\frac{mg}{m^e-air}\right]}{VF_{sesp}}$$

where:
$RBSL_{svin}$ = Risk based screening level (volatilization to indoor air pathway)

Fraction-specific RBSLs are then used to calculate the "whole TPH" RBSLs.

Volatilization to Outdoor Air Pathway

The volatilization to outdoor air model is similar to the indoor air model. It assumes contaminants partition into soil pore gas which migrates through the vadose zone to the surface and mixes with the ambient air. Dispersion into ambient air is modeled using a "box model", which is typically valid for source widths of less than 100 feet parallel to wind direction. Steady-state well-mixed atmospheric dispersion of the vapors within the breathing zone is assumed. Other assumptions listed for the indoor air model include linear equilibrium partitioning, steady-state vapor diffusion through the vadose zone and no attenuation of the chemical as it migrates through the vadose zone.

The calculation of a soil RBSL protective of outdoor air quality is similar to that used for the indoor air pathway. A volatilization factor for ambient air (VF_{samb}) is derived, using the same effective diffusion coefficient in vadose soils and partitioning factor. Default values are provided in Table B-2.

$$VF_{samb}\left[\frac{mg/m^3-air}{mg/kg-soil}\right]=\frac{PF_{S-V}}{1+\frac{U_{air}\delta_{air}L_S}{D^{eff}_S\,w}}\times 10^3\left[\frac{cm^3-kg}{m^3-g}\right]$$

where:
$PF_{s\text{-}v}$ = Soil/Vapor phase partitioning factor [unitless]
D^{eff}_s = Effective diffusion coefficient in soil [cm^2/s]
U_{air} = Wind speed above ground surface in ambient mixing zone [cm/s]
δ_{air} = Ambient air mixing zone height [cm]
w = Width of source area parallel to wind direction [cm]

VF_{samb} is then combined with the allowable concentration of contaminant in the air space ($RBSL_{air}$) to determine the maximum allowable concentration of contaminant in the subsurface soil ($RBSL_{svout}$), as shown below:

$$RBSL_{svout} = \frac{RBSL_{air}\left[\frac{mg}{m^{e}-air}\right]}{VF_{samb}}$$

Fraction-specific RBSLs are then used to calculate "whole TPH" RBSLs. Parameter values are presented in Table B-2.

Direct Contact Pathway

For direct exposure routes such as soil ingestion, dermal absorption and inhalation of particulates, exposure is not limited by C_{sat}. The assumption is made that intake will continue to increase linearly with soil loading beyond C_{sat} for ingestion, dermal and particulate inhalation pathways. For the direct contact pathways, the following equations are solved:

$$HI = \sum_{i=1}^{i=n} HQ_i = \sum_{i=1}^{i=n} \frac{f_i C_{TPH}}{RBSL_i} \leq 1$$

$$RBSL_{ss}\left[\frac{ug}{kg-soil}\right] = \frac{THQ \times BW \times AT_n \times 365\ {}^{days}\!/_{yr}}{EF \times ED \times \left[\frac{10^{-6}\ {}^{kg}\!/_{mg} \times (IR_{soil} \times RAF_o \times SA \times M \times RAF_d)}{RfD_o}\right] + \left[\frac{IR_{air} \times (VF_{ss} + VF_p)}{RfD_i}\right]}$$

where:

THQ = Target hazard quotient for constituent [unitless]
BW = Body weight [kg]
AT_n = Averaging time for noncarcinogens [years]
EF = Exposure frequency (days/year]
ED = Exposure duration [years]
IR_{soil} = Soil ingestion rate [mg/day]
RAF_o = Relative oral absorption factor [unitless]
SA = Skin surface area [cm^2/day]
M = Soil to skin adherence factor [mg/cm^2]
RAF_d = Relative dermal absorption factor [unitless]
RfD_o = Oral chronic reference dose [mg/kg-day]
IR_{air} = Inhalation rate [m^3/day]
VF_{ss} = Surficial soils to ambient air partition factor (vapor) [unitless]
VF_p = Surficial soils to ambient air partition factor [unitless]
RfD_i = Inhalation chronic reference dose [mg/kg-day]

Similar to the HI calculation, the RBSL equation is solved iteratively to find C_{TPH} such that HI=1 under the constraint of a target hazard index of 1.0. Default exposure parameters are provided in Table B-1. The fraction specific RfDs are provided in Table 3-2.

APPENDIX C

RBCA MODEL RUNS

RBCA Model Runs

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RESIDENTIAL SCENARIO

	Csat (mg/kg)	RBSL.R.11 s lch (mg/kg) HQ=1	RBSL.R.16 s v out (mg/kg) HQ=1	RBSL.R.16 s v in (mg/kg) HQ=1	RBSL.R.18 ss (mg/kg) HQ=1
5-6 Aliphatics	4.76E+02	2.92E+04	2.73E+03	5.43E+01	3.53E+05
5-7 Aromatics	1.63E+03	8.11E+01	6.50E+02	1.29E+01	1.24E+04
>6-8 Aliphatics	2.57E+02	1.05E+05	6.56E+03	1.31E+02	3.53E+05
>7-8 Aromatics	1.26E+03	2.17E+02	1.46E+03	2.92E+01	1.24E+04
>8-10 Aliphatics	1.41E+02	1.45E+04	1.69E+03	3.36E+01	7.78E+03
>8-10 Aromatics	1.04E+03	2.83E+02	2.29E+03	4.56E+01	2.91E+03
>10-12 Aliphatics	8.61E+01	1.12E+05	8.20E+03	1.63E+02	7.78E+03
>10-12 Aromatics	6.30E+02	4.46E+02	1.26E+04	2.52E+02	2.91E+03
>12-16 Aliphatics	3.82E+01	2.22E+06	3.91E+04	7.79E+02	7.78E+03
>12-16 Aromatics	2.91E+02	8.88E+02	6.52E+04	1.30E+03	3.01E+03
>16-21 Aliphatics	1.30E+01	8.84E+09	4.39E+06	8.73E+04	1.51E+05
>16-21 Aromatics	8.09E+01	2.10E+03	5.56E+05	1.11E+04	2.39E+03
>21-35 Aromatics	8.31E+00	1.67E+04	7.71E+07	1.53E+06	2.45E+03

	Fraction (mg/kg/mg/kg)	HQ(Ci)	HQ(Ci)	HQ(Ci)	HQ(Ci)
5-6 Aliphatics	0.00E+00	0.00%	0.00E+00	0.00E+00	0.00E+00
5-7 Aromatics	0.00E+00	0.00%	0.00E+00	0.00E+00	0.00E+00
>6-8 Aliphatics	1.07E-01	0.24%	3.93E-02	1.30E-01	2.31E-03
>7-8 Aromatics	8.57E-04	1.44%	3.57E-01	4.66E-03	5.24E-04
>8-10 Aliphatics	1.09E-01	0.97%	8.38E-02	5.14E-01	1.06E-01
>8-10 Aromatics	2.27E-02	29.35%	4.54E-01	7.91E-02	5.94E-02
>10-12 Aliphatics	1.91E-01	0.08%	1.05E-02	1.85E-01	1.86E-01
>10-12 Aromatics	4.29E-02	35.11%	4.99E-02	2.70E-02	1.12E-01
>12-16 Aliphatics	3.12E-01	0.00%	9.75E-04	4.90E-02	3.04E-01
>12-16 Aromatics	8.84E-02	32.80%	4.46E-03	1.08E-02	2.23E-01
>16-21 Aliphatics	1.26E-01	0.00%	2.96E-06	1.49E-04	6.34E-03
>16-21 Aromatics	0.00E+00	0.00%	0.00E+00	0.00E+00	0.00E+00
>21-35 Aromatics	0.00E+00	0.00%	0.00E+00	0.00E+00	0.00E+00
Total	1.00E+00				

	RBSL.R.11 s lch (mg/kg)	RBSL.R.16 s v out (mg/kg)	RBSL.R.16 s v in (mg/kg)	RBSL.R.18 ss (mg/kg)
HI	1.00E+00	1.00E+00	1.00E+00	1.00E+00
RBSL(HI=1) mg/kg	3,649	610,733	159	7,588

COMMERCIAL SCENARIO

	Csat (mg/kg)	RBSL.C.11 s lch (mg/kg) Non-Carc	RBSL.C.16 s v out (mg/kg) Non-Carc	RBSL.C.16 s v in (mg/kg) Non-Carc	RBSL.C.18 ss (mg/kg) Non-Carc
5-6 Aliphatics	4.76E+02	8.18E+04	3.82E+03	1.40E+02	5.19E+05
5-7 Aromatics	1.63E+03	2.27E+02	9.10E+02	3.35E+01	1.81E+04
>6-8 Aliphatics	2.57E+02	2.95E+05	9.18E+03	3.38E+02	5.19E+05
>7-8 Aromatics	1.26E+03	6.07E+02	2.05E+03	7.55E+01	1.81E+04
>8-10 Aliphatics	1.41E+02	4.07E+04	2.36E+03	8.70E+01	1.15E+04
>8-10 Aromatics	1.04E+03	7.92E+02	3.21E+03	1.18E+02	4.28E+03
>10-12 Aliphatics	8.61E+01	3.13E+05	1.15E+04	4.22E+02	1.15E+04
>10-12 Aromatics	6.30E+02	1.25E+03	1.77E+04	6.51E+02	4.28E+03
>12-16 Aliphatics	3.82E+01	6.21E+06	5.48E+04	2.02E+03	1.15E+04
>12-16 Aromatics	2.91E+02	2.49E+03	9.13E+04	3.36E+03	4.44E+03
>16-21 Aliphatics	1.30E+01	2.48E+10	6.14E+06	2.26E+05	2.23E+05
>16-21 Aromatics	8.09E+01	5.89E+03	7.78E+05	2.86E+04	3.54E+03
>21-35 Aromatics	8.31E+00	4.67E+04	1.08E+08	3.97E+06	3.64E+03

	Fraction (mg/kg/mg/kg)	HQ(Ci)	HQ(Ci)	HQ(Ci)	HQ(Ci)
5-6 Aliphatics	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5-7 Aromatics	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
>6-8 Aliphatics	1.07E-01	8.73E-04	2.80E-02	1.35E-01	2.32E-03
>7-8 Aromatics	8.57E-04	1.92E-02	5.41E-01	4.81E-03	5.30E-04
>8-10 Aliphatics	1.09E-01	3.47E-03	5.98E-02	5.30E-01	1.06E-01
>8-10 Aromatics	2.27E-02	3.91E-01	3.24E-01	8.16E-02	5.96E-02
>10-12 Aliphatics	1.91E-01	2.75E-04	7.50E-03	1.91E-01	1.86E-01
>10-12 Aromatics	4.29E-02	4.68E-01	3.56E-02	2.79E-02	1.12E-01
>12-16 Aliphatics	3.12E-01	6.14E-06	6.96E-04	1.89E-02	3.04E-01
>12-16 Aromatics	8.84E-02	1.17E-01	3.19E-03	1.11E-02	2.23E-01
>16-21 Aliphatics	1.26E-01	5.25E-10	2.12E-06	5.75E-05	6.34E-03
>16-21 Aromatics	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
>21-35 Aromatics	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	1.00E+00				

	RBSL.C.11 s lch (mg/kg)	RBSL.C.16 s v out (mg/kg)	RBSL.C.16 s v in (mg/kg)	RBSL.C.18 ss (mg/kg)
HI	1.00E+00	1.00E+00	1.00E+00	1.00E+00
RBSL(HI=1) mg/kg	13,615	1,294,669	423	11,208

RBCA Model Runs

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RESIDENTIAL SCENARIO

	Csat	RBSL.R.11	RBSL.R.16	RBSL.R.16	RBSL.R.18
		s lch	s v out	s v in	ss
	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
		HQ=1	HQ=1	HQ=1	HQ=1
5-6 Aliphatics	4.76E+02	2.92E+04	2.73E+03	5.43E+01	3.53E+05
5-7 Aromatics	1.63E+03	8.11E+01	6.50E+02	1.29E+01	1.24E+04
>6-8 Aliphatics	2.57E+02	1.05E+05	6.56E+03	1.31E+02	3.53E+05
>7-8 Aromatics	1.26E+03	2.17E+02	1.46E+03	2.92E+01	1.24E+04
>8-10 Aliphatics	1.41E+02	1.45E+04	1.69E+03	3.36E+01	7.78E+03
>8-10 Aromatics	1.04E+03	2.83E+02	2.29E+03	4.56E+01	2.91E+03
>10-12 Aliphatics	8.61E+01	1.12E+05	8.20E+03	1.63E+02	7.78E+03
>10-12 Aromatics	6.30E+02	4.46E+02	1.26E+04	2.52E+02	2.91E+03
>12-16 Aliphatics	3.82E+01	2.22E+06	3.91E+04	7.79E+02	7.78E+03
>12-16 Aromatics	2.91E+02	8.88E+02	6.52E+04	1.30E+03	3.01E+03
>16-21 Aliphatics	1.30E+01	8.84E+09	4.39E+06	8.73E+04	1.51E+05
>16-21 Aromatics	8.09E+01	2.10E+03	5.56E+05	1.11E+04	2.39E+03
>21-35 Aromatics	8.31E+00	1.67E+04	7.71E+07	1.53E+06	2.45E+03

	Fraction (mg/kg/mg/kg)	HQ(Ci)	HQ(Ci)	HQ(Ci)	HQ(Ci)
5-6 Aliphatics	2.43E-02	0.21%	1.74E-01	4.16E-02	5.45E-04
5-7 Aromatics	2.25E-03	6.97%	7.67E-02	1.62E-02	1.44E-03
>6-8 Aliphatics	2.02E-01	0.24%	3.93E-02	1.44E-01	4.53E-03
>7-8 Aromatics	9.20E-03	10.65%	1.39E-01	2.94E-02	5.89E-03
>8-10 Aliphatics	1.89E-01	0.97%	8.38E-02	5.24E-01	1.93E-01
>8-10 Aromatics	4.35E-02	38.61%	4.21E-01	8.88E-02	1.19E-01
>10-12 Aliphatics	2.01E-01	0.08%	1.05E-02	1.15E-01	2.05E-01
>10-12 Aromatics	5.11E-02	28.75%	4.99E-02	1.89E-02	1.39E-01
>12-16 Aliphatics	1.66E-01	0.00%	9.75E-04	1.98E-02	1.69E-01
>12-16 Aromatics	4.15E-02	11.74%	4.46E-03	2.97E-03	1.10E-01
>16-21 Aliphatics	5.49E-02	0.00%	2.96E-06	5.84E-05	2.88E-03
>16-21 Aromatics	1.49E-02	1.77%	1.45E-04	1.25E-04	4.94E-02
>21-35 Aromatics	0.00E+00	0.00%	0.00E+00	0.00E+00	0.00E+00
Total	1.00E+00				
		RBSL.R.11	RBSL.R.16	RBSL.R.16	RBSL.R.18
		s lch	s v out	s v in	ss
		(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
HI		1.00E+00	1.00E+00	1.00E+00	1.00E+00
RBSL(HI=1) mg/kg		2,509	22,141	93	7,932

COMMERCIAL SCENARIO

	Csat	RBSL.C.11	RBSL.C.16	RBSL.C.16	RBSL.C.18
		s lch	s v out	s v in	ss
	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
		Non-Carc	Non-Carc	Non-Carc	Non-Carc
5-6 Aliphatics	4.76E+02	8.18E+04	3.82E+03	1.40E+02	5.19E+05
5-7 Aromatics	1.63E+03	2.27E+02	9.10E+02	3.35E+01	1.81E+04
>6-8 Aliphatics	2.57E+02	2.95E+05	9.18E+03	3.38E+02	5.19E+05
>7-8 Aromatics	1.26E+03	6.07E+02	2.05E+03	7.55E+01	1.81E+04
>8-10 Aliphatics	1.41E+02	4.07E+04	2.36E+03	8.70E+01	1.15E+04
>8-10 Aromatics	1.04E+03	7.92E+02	3.21E+03	1.18E+02	4.28E+03
>10-12 Aliphatics	8.61E+01	3.13E+05	1.15E+04	4.22E+02	1.15E+04
>10-12 Aromatics	6.30E+02	1.25E+03	1.77E+04	6.51E+02	4.28E+03
>12-16 Aliphatics	3.82E+01	6.21E+06	5.48E+04	2.02E+03	1.15E+04
>12-16 Aromatics	2.91E+02	2.49E+03	9.13E+04	3.36E+03	4.44E+03
>16-21 Aliphatics	1.30E+01	2.48E+10	6.14E+06	2.26E+05	2.23E+05
>16-21 Aromatics	8.09E+01	5.89E+03	7.78E+05	2.86E+04	3.54E+03
>21-35 Aromatics	8.31E+00	4.67E+04	1.08E+08	3.97E+06	3.64E+03

	Fraction (mg/kg/mg/kg)	HQ(Ci)	HQ(Ci)	HQ(Ci)	HQ(Ci)
5-6 Aliphatics	2.43E-02	2.12E-03	1.25E-01	4.16E-02	5.48E-04
5-7 Aromatics	2.25E-03	7.07E-02	1.79E+00	1.62E-02	1.45E-03
>6-8 Aliphatics	2.02E-01	8.73E-04	2.80E-02	1.44E-01	4.55E-03
>7-8 Aromatics	9.20E-03	1.08E-01	6.16E-01	2.94E-02	5.95E-03
>8-10 Aliphatics	1.89E-01	3.47E-03	5.98E-02	5.24E-01	1.93E-01
>8-10 Aromatics	4.35E-02	3.92E-01	3.24E-01	8.89E-02	1.19E-01
>10-12 Aliphatics	2.01E-01	2.75E-04	7.50E-03	1.15E-01	2.05E-01
>10-12 Aromatics	5.11E-02	2.92E-01	3.56E-02	1.89E-02	1.40E-01
>12-16 Aliphatics	1.66E-01	6.14E-06	6.96E-04	1.89E-02	1.69E-01
>12-16 Aromatics	4.15E-02	1.17E-01	3.19E-03	2.98E-03	1.10E-01
>16-21 Aliphatics	5.49E-02	5.25E-10	2.12E-06	5.75E-05	2.89E-03
>16-21 Aromatics	1.49E-02	1.37E-02	1.04E-04	1.25E-04	4.93E-02
>21-35 Aromatics	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	1.00E+00				
		RBSL.C.11	RBSL.C.16	RBSL.C.16	RBSL.C.18
		s lch	s v out	s v in	ss
		(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
HI		1.00E+00	2.99E+00	1.00E+00	1.00E+00
RBSL(HI=1) mg/kg		7,129	1,049,713	241	11,716

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RESIDENTIAL SCENARIO

	Csat	RBSL.R.11	RBSL.R.16	RBSL.R.16	RBSL.R.18
		s lch	s v out	s v in	ss
	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
		HQ=1	HQ=1	HQ=1	HQ=1
5-6 Aliphatics	4.76E+02	2.92E+04	2.73E+03	5.43E+01	3.53E+05
5-7 Aromatics	1.63E+03	8.11E+01	6.50E+02	1.29E+01	1.24E+04
>6-8 Aliphatics	2.57E+02	1.05E+05	6.56E+03	1.31E+02	3.53E+05
>7-8 Aromatics	1.26E+03	2.17E+02	1.46E+03	2.92E+01	1.24E+04
>8-10 Aliphatics	1.41E+02	1.45E+04	1.69E+03	3.36E+01	7.78E+03
>8-10 Aromatics	1.04E+03	2.83E+02	2.29E+03	4.56E+01	2.91E+03
>10-12 Aliphatics	8.61E+01	1.12E+05	8.20E+03	1.63E+02	7.78E+03
>10-12 Aromatics	6.30E+02	4.46E+02	1.26E+04	2.52E+02	2.91E+03
>12-16 Aliphatics	3.82E+01	2.22E+06	3.91E+04	7.79E+02	7.78E+03
>12-16 Aromatics	2.91E+02	8.88E+02	6.52E+04	1.30E+03	3.01E+03
>16-21 Aliphatics	1.30E+01	8.84E+09	4.39E+06	8.73E+04	1.51E+05
>16-21 Aromatics	8.09E+01	2.10E+03	5.56E+05	1.11E+04	2.39E+03
>21-35 Aromatics	8.31E+00	1.67E+04	7.71E+07	1.53E+06	2.45E+03

	Fraction	HQ(Ci)	HQ(Ci)	HQ(Ci)	HQ(Ci)
	(mg/kg/mg/kg)				
5-6 Aliphatics	2.85E-02	0.30%	1.74E-01	5.21E-02	6.13E-04
5-7 Aromatics	0.00E+00	0.00%	0.00E+00	0.00E+00	0.00E+00
>6-8 Aliphatics	1.82E-01	0.24%	3.93E-02	1.38E-01	3.91E-03
>7-8 Aromatics	0.00E+00	0.00%	0.00E+00	0.00E+00	0.00E+00
>8-10 Aliphatics	1.75E-01	0.97%	8.38E-02	5.15E-01	1.70E-01
>8-10 Aromatics	3.47E-02	38.10%	4.54E-01	7.54E-02	9.06E-02
>10-12 Aliphatics	2.74E-01	0.08%	1.05E-02	1.67E-01	2.68E-01
>10-12 Aromatics	6.19E-02	43.21%	4.99E-02	2.44E-02	1.62E-01
>12-16 Aliphatics	1.86E-01	0.00%	9.75E-04	2.37E-02	1.82E-01
>12-16 Aromatics	4.88E-02	17.09%	4.46E-03	3.73E-03	1.23E-01
>16-21 Aliphatics	9.25E-03	0.00%	2.96E-06	1.05E-05	4.66E-04
>16-21 Aromatics	0.00E+00	0.00%	0.00E+00	0.00E+00	0.00E+00
>21-35 Aromatics	0.00E+00	0.00%	0.00E+00	0.00E+00	0.00E+00
Total	1.00E+00				

		RBSL.R.11	RBSL.R.16	RBSL.R.16	RBSL.R.18
		s lch	s v out	s v in	ss
		(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
HI		1.00E+00	8.17E-01	1.00E+00	1.00E+00
RBSL(HI=1) mg/kg		3,109	657,971	99	7,593

COMMERCIAL SCENARIO

	Csat	RBSL.C.11	RBSL.C.16	RBSL.C.16	RBSL.C.18
		s lch	s v out	s v in	ss
	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
		Non-Carc	Non-Carc	Non-Carc	Non-Carc
5-6 Aliphatics	4.76E+02	8.18E+04	3.82E+03	1.40E+02	5.19E+05
5-7 Aromatics	1.63E+03	2.27E+02	9.10E+02	3.35E+01	1.81E+04
>6-8 Aliphatics	2.57E+02	2.95E+05	9.18E+03	3.38E+02	5.19E+05
>7-8 Aromatics	1.26E+03	6.07E+02	2.05E+03	7.55E+01	1.81E+04
>8-10 Aliphatics	1.41E+02	4.07E+04	2.36E+03	8.70E+01	1.15E+04
>8-10 Aromatics	1.04E+03	7.92E+02	3.21E+03	1.18E+02	4.28E+03
>10-12 Aliphatics	8.61E+01	3.13E+05	1.15E+04	4.22E+02	1.15E+04
>10-12 Aromatics	6.30E+02	1.25E+03	1.77E+04	6.51E+02	4.28E+03
>12-16 Aliphatics	3.82E+01	6.21E+06	5.48E+04	2.02E+03	1.15E+04
>12-16 Aromatics	2.91E+02	2.49E+03	9.13E+04	3.36E+03	4.44E+03
>16-21 Aliphatics	1.30E+01	2.48E+10	6.14E+06	2.26E+05	2.23E+05
>16-21 Aromatics	8.09E+01	5.89E+03	7.78E+05	2.86E+04	3.54E+03
>21-35 Aromatics	8.31E+00	4.67E+04	1.08E+08	3.97E+06	3.64E+03

	Fraction	HQ(Ci)	HQ(Ci)	HQ(Ci)	HQ(Ci)
	(mg/kg/mg/kg)				
5-6 Aliphatics	2.85E-02	3.26E-03	1.25E-01	5.24E-02	6.15E-04
5-7 Aromatics	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
>6-8 Aliphatics	1.82E-01	8.73E-04	2.80E-02	1.39E-01	3.93E-03
>7-8 Aromatics	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
>8-10 Aliphatics	1.75E-01	3.47E-03	5.98E-02	5.18E-01	1.70E-01
>8-10 Aromatics	3.47E-02	4.10E-01	3.24E-01	7.58E-02	9.08E-02
>10-12 Aliphatics	2.74E-01	2.75E-04	7.50E-03	1.68E-01	2.67E-01
>10-12 Aromatics	6.19E-02	4.65E-01	3.56E-02	2.46E-02	1.62E-01
>12-16 Aliphatics	1.86E-01	6.14E-06	6.96E-04	1.89E-02	1.81E-01
>12-16 Aromatics	4.88E-02	1.17E-01	3.19E-03	3.75E-03	1.23E-01
>16-21 Aliphatics	9.25E-03	5.25E-10	2.12E-06	1.06E-05	4.66E-04
>16-21 Aromatics	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
>21-35 Aromatics	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	1.00E+00				

		RBSL.C.11	RBSL.C.16	RBSL.C.16	RBSL.C.18
		s lch	s v out	s v in	ss
		(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
HI		1.00E+00	5.84E-01	1.00E+00	1.00E+00
RBSL(HI=1) mg/kg		9,368	2,099,426	258	11,215