Petroleum Hydrocarbons Using the EPH/VPH/APH Analytical Methods and Criteria Development

TECHNICAL SUPPORT DOCUMENT

Connecticut Department of Energy and Environmental Protection
Connecticut Department of Public Health
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Background and Analytical Considerations

The Connecticut Remediation Standard Regulations, Sections 22a-133k-1 through 22a-133k-3 of the Regulations of Connecticut State Agencies (RSRs), contain environmental criteria to facilitate the assessment and remediation, as necessary, at sites within Connecticut which have been affected by releases of various substances. Within the regulations promulgated in 1996, criteria were established for certain individual semi-volatile substances commonly associated with releases of petroleum hydrocarbon mixtures in addition to criteria for Total Petroleum Hydrocarbons (TPH) as a complex aggregate of substances as reported by the United States Environmental Protection Agency (EPA) Method 418.1, which utilized Freon-111. In an effort to help bring about the end of Freon use in Connecticut and to be consistent with Federal Law, the Connecticut Department of Energy and Environmental Protection (DEEP) stopped accepting analytical data derived by EPA Method 418.1 for samples collected on or after June 30, 2009. In addition, the Environmental Laboratory Certification Program of the Connecticut Department of Public Health stopped offering certification for EPA Method 418.1 as of September 30, 2009 and after this deadline laboratories may not use EPA Method 418.1. Since the TPH remediation criteria in the regulations were method specific, and laboratories could no longer use EPA Method 418.1, this effectively prevented the use of the promulgated criteria from use at remediation sites for samples collected on or after June 30, 2009.

Since 1999, another analytical method has been available for use in Connecticut to evaluate petroleum hydrocarbons as a complex mixture of aggregate of substances. This method is titled "Analysis of Extractable Total Petroleum Hydrocarbons Using Methylene Chloride Gas Chromatograph/Flame Ionization Detection (ETPH Method)," prepared by the Environmental Research Institute, University of Connecticut, dated March 1999 and approved by the Commissioner of the State of Connecticut Department of Public Health (CT DPH) on June 22, 1999. Certain remediation criteria using the ETPH Method were recommended at that time for the Extractable Total Petroleum Hydrocarbons fraction (ETPH) and have been available for use with site-specific approval at remediation sites. *The ETPH Method reports ETPH which is different from TPH as reported by* EPA Method 418.1

At this time DEEP intends to propose adoption of remediation criteria based on the ETPH Method into the RSRs. Information regarding the proposed criteria is available in document titled *Extractable Petroleum Hydrocarbon Fractions Using the ETPH Analytical Method and Criteria Development*.

Additionally, in 1997, the Massachusetts Department of Environmental Protection (MA DEP) developed risk-based criteria and new analytical methods which focused on quantifying petroleum hydrocarbons based on the number of carbon atoms within the hydrocarbon molecule and consideration of whether the fraction was extractable, volatile or in a gaseous phase. These methods, referred to as the Extractable Petroleum Hydrocarbon (EPH), Volatile Petroleum Hydrocarbon (VPH), and Air-Phase Petroleum Hydrocarbon (APH) methods, which address extractable, volatile and air-phase petroleum hydrocarbon fractions, are also available for use with site-specific approval at remediation sites. The Reasonable Confidence Protocols

(RCPs) for the EPH, VPH and APH methods were finalized in May 2009 and are available on DEEP's website. The Connecticut Reasonable Confidence Protocol for the APH method is expected to be released for public comment in the future.

Criteria for petroleum hydrocarbons are developed to complement the analytical methods used to determine the amount of petroleum hydrocarbons present. Since, petroleum hydrocarbons are a complex aggregate of substances, the results of petroleum hydrocarbon analyses differ depending on the analytical method used, with each method targeting a slightly different subset of the full amount of petroleum hydrocarbons potentially present. DEEP is identifying petroleum hydrocarbon criteria based on the analytical methods identified in Table 1 which may be used at remediation sites on a case-by-case basis.

Table 1. Analytical Methods for Petroleum Hydrocarbons

Method Name	Method Developed By	Petroleum Hydrocarbon Fractions Analyzed
EPH: Extractable Petroleum Hydrocarbons	MA DEP; CT Reasonable Confidence Protocol available on DEEP Website	This method is used to quantify individual fractions of extractable aliphatic and aromatic hydrocarbons in water, soil or sediments, based on the number of carbon atoms included in the constituent compounds. The method quantifies extractable aliphatic hydrocarbons within two specific ranges: C_9 through C_{18}, and C_{19} through C_{36}. Additionally, extractable aromatic hydrocarbons are quantified within the C_{11} through C_{22} range.
VPH: Volatile Petroleum Hydrocarbons	MA DEP; CT Reasonable Confidence Protocol available on DEEP Website	This method is used to quantify individual fractions of volatile aliphatic and aromatic hydrocarbons in water, soil or sediments, based on the number of carbon atoms included in the constituent compounds. The method quantifies volatile aliphatic hydrocarbons within two specific ranges: C_5 through C_8, and C_9 through C_{12}. Additionally, volatile aromatic hydrocarbons are quantified within the C_9 through C_{10} range.
APH: Air Phase Petroleum Hydrocarbons	MA DEP	This method is used to quantify individual fractions of gaseous phase volatile aliphatic and aromatic hydrocarbons based on the number of carbon atoms includes in the constituent compounds. The method quantified aliphatic hydrocarbons within two specific ranges: C_5 through C_8, and C_9 through C_{12}. Additionally, aromatic hydrocarbons are quantified within the C_9 through C_{10} range.

Additional guidance on the implementation of these methods and criteria into remediation projects and analytical quality assurance guidance are provided in separate documents, available on the DEEP website as well as in Appendix A to this document.

Due to these changes in analytical methods used to characterize releases of petroleum hydrocarbons, address the need to incorporate self-implementing criteria for petroleum hydrocarbons within the RSRs, and provide flexibility regarding implementation of new criteria, DEEP is proposing:

1) to adopt within the RSRs criteria for extractable fraction of petroleum hydrocarbons using the ETPH Method. Information on the proposed criteria is available on the DEEP website in *Extractable Petroleum Hydrocarbon Fractions Using the ETPH Analytical Method and Criteria Development*.

2) to provide guidance regarding recommended criteria for extractable, volatile and air phase petroleum hydrocarbons using the EPH, VPH, and APH methods for use, on a case-by-case basis, at sites for which such criteria are needed. Use of recommended criteria would allow for a rapid review and approval process for site-specific criteria. Supporting documentation regarding the derivation of recommended remediation criteria for use with the EPH/VPH/APH methods is provided in this document. In lieu of using these recommended criteria, different site-specific criteria may be developed and submitted for review and approval of the Commissioner using the processes specified within the RSRs.

Derivation of Remediation Criteria for Petroleum Hydrocarbons

Risk-based criteria are derived using data and assumptions to define those potentially exposed to contaminated environmental media, the rate at which the exposure may occur, and the toxicity of the substance. Derivation of risk-based remediation criteria for petroleum hydrocarbons using EPH/VPH/APH analytical methods, including Direct Exposure Criteria, Pollutant Mobility Criteria, Groundwater Protection Criteria, Surface Water Protection Criteria, Groundwater Volatilization Criteria and Soil Vapor Volatilization Criteria, are proposed using the updated toxicity values presented below.

Toxicity Values

The human health toxicity values adopted by MA DEP in the 2005 revisions to the Massachusetts Contingency Plan and described in the 2003 MA DEP publication entitled, Updated Petroleum Hydrocarbon Fraction Toxicity Values for the VPH/EPH/APH Methodology, were reviewed. Since remediation criteria developed for these methods are applicable to a broad range of compounds within each hydrocarbon fraction, a toxicity value based on a representative compound is selected as a surrogate for the various substances within the each hydrocarbon fraction. Toxicity values identified by MA DEP were selected for use in deriving the proposed Connecticut criteria for petroleum hydrocarbons using EPH/VPH/APH analyses except for the oral and inhalation toxicity values for the aromatic hydrocarbon fractions for which updated toxicity information is available.

Oral Reference Dose for Aromatic Hydrocarbon Fractions (C_9-C_{22}) in EPH and VPH Analyses

MA DEP identified 8 aromatic hydrocarbon compounds within this range for which the EPA established oral reference dose values. These compounds are acenaphthene, anthracene, biphenyl, fluorene, fluoranthene, isopropylbenzene (cumene), naphthalene and pyrene. In the derivation of their criteria for this fraction, MA DEP selected toxicity values based on a study of naphthalene and methylnaphthalene.

However, there are several compounds within this fraction for which the toxicological literature is robust, providing a higher level of confidence for the estimate of toxicity of substances. For this reason, DEEP in consultation with CT DPH has selected 1,3,5-trimethyl benzene and naphthalene as a surrogates for the C_9-C_{10} and C_{11}-C_{22} aromatic hydrocarbon fractions, respectively, instead of naphthalene and methylnaphthalene as used by MA DEP for these fractions. DEEP selected naphthalene as the surrogate for the C_{11}-C_{22} aromatic fraction in spite of the fact that it is a C_{10} hydrocarbon, because it is a multi-ringed structure and thus more similar to the constituents in the C_{11}-C_{22} aromatic fraction than it is to the C_9-C_{10} aromatic fraction which is more typically composed of alkylbenzenes which are not multi-ringed structures. This is similar to the approach used by MA DEP and in Agency for Toxic Substances and Disease Registry (ATSDR) Toxicological Profile (1999) approach in which naphthalene was used to represent the C_9-C_{16} aromatic fraction.

Updated oral reference dose (RfD) values for both naphthalene and 1,3,5-trimethylbenzene were obtained from EPA using either the Integrated Risk Information System (IRIS) or from toxicity values used by EPA to derive EPA Regional Screening Levels for Chemical Contaminants at Superfund Sites, updated November 2011, and are shown in Table 2.

Inhalation Reference Dose for Aromatic Hydrocarbon Fractions (C_9-C_{22}) in EPH and VPH Analyses

Inhalation toxicity values for four substances were evaluated by MA DEP in the development of their criteria. The compounds evaluated were isopropylbenzene (cumene), naphthalene, trimethylbenzene and high flash aromatic naphtha, and the toxicity data is presented in Table 15 of Updated Petroleum Hydrocarbon Fraction Toxicity Values for the VPH/EPH/APH Methodology (MA DEP 2003), appended to this document in Appendix B for convenience. This table shows that there is a wide range in toxicological estimates for aromatic hydrocarbon substances within this fraction. Also, additional information is available from EPA, published in the Regional Screening Levels for Chemical Contaminants at Superfund Sites, updated November 2011, which provides additional toxicity values for trimethylbenzene compounds. EPA has identified inhalation reference doses (RfC) of 0.005 mg/m^3 for 1,2,3-trimethylbenzene and 0.007 mg/m^3 for 1,2,4-trimethylbenzene, as compared with the toxicity value of 0.02 mg/m^3 identified for trimethylbenzene in Table 15 of the MA DEP document. A further consideration is that DEEP uses a target indoor air concentration for isopropylbenzene of 0.04 mg/m^3 rather than the inhalation reference dose - based target of 0.4 mg/m^3 because of isopropylbenzene's low odor threshold. By consideration of odor thresholds the criteria is intended to avoid obvious hydrocarbon contamination of indoor air. When considering the range of inhalation toxicity values presented by MA DEP (their Table 15) in conjunction with recent toxicology updates from EPA and the goal of preventing petroleum-related odors, DEEP in consultation with CT DPH recommend using a value of 0.025 mg/m^3 as a central tendency estimate for substances within this range.

Table 2. Toxicity Values for Use in Deriving Petroleum Hydrocarbons Criteria Using EPH/VPH/APH Methodologies

Hydrocarbon Fraction	Oral Surrogate	Method	Oral Reference Dose (mg/kg/d)	Source	Inhalation Surrogate	Inhalation Reference Dose (mg/m^3)	Source
Aliphatic: C_5-C_8	n-Hexane	VPH	0.04	MA DEP	n-Hexane	0.2	MA DEP
Aliphatic: C_9-C_{12}	Dearomatized White Spirits	VPH	0.1	MA DEP	Dearomatized White Spirits	0.2	MA DEP
Aliphatic: C_9-C_{18}	Dearomatized White Spirits	EPH	0.1	MA DEP	Dearomatized White Spirits	0.2	MA DEP
Aliphatic: C_{19}-C_{36}	Mineral Spirits	EPH	2	MA DEP	Mineral Spirits	Not Volatile	
Aromatic: C_9-C_{10}	1,3,5-Trimethyl Benzene	VPH	0.01	EPA RSL	Multiple – see text	0.025	EPA - see text
Aromatic: C_{11}-C_{22}	Naphthalene	EPH	0.02	IRIS	Multiple – see text	0.025	EPA – see text

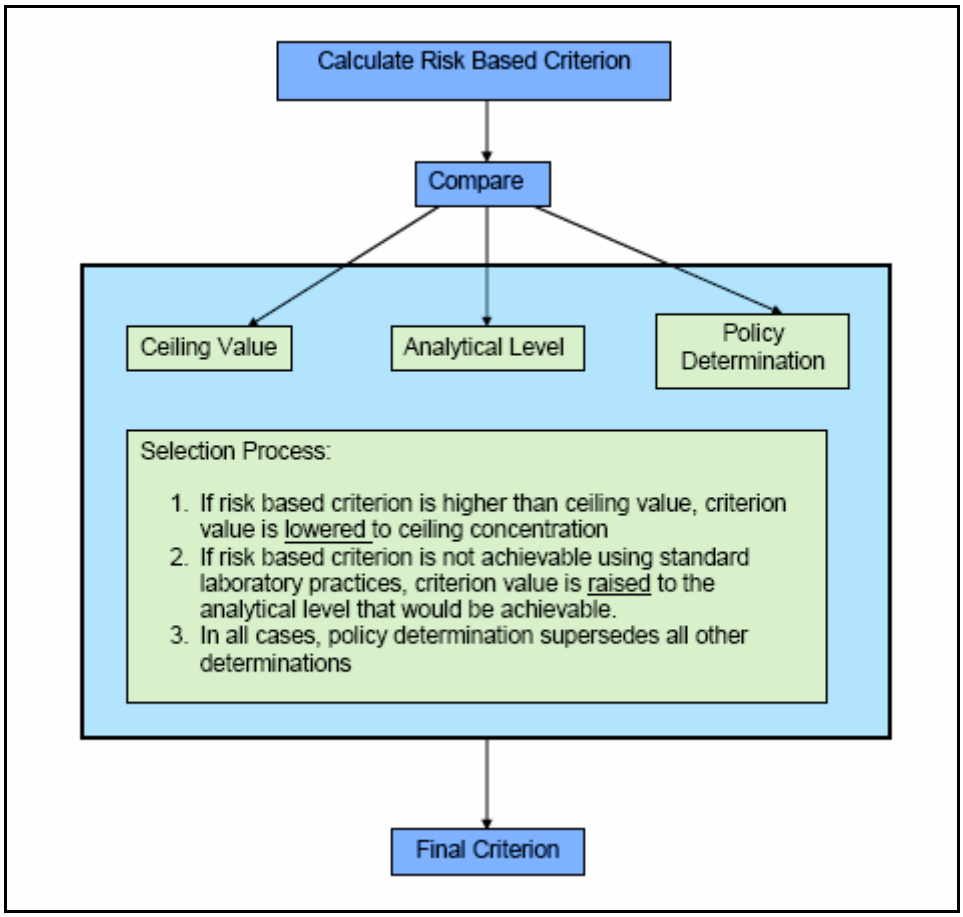
MA DEP: Massachusetts Department of Environmental Protection Updated Hydrocarbon Fraction Toxicity Values 2003
EPA RSL: EPA Regional Screening Levels Documentation 2011
IRIS: EPA Integrated Risk Information System

Calculation of Risk-Based Criteria for Petroleum Hydrocarbons

The equations and exposure-based inputs used to derive the risk-based criteria are set forth in the appendices attached to this document to clearly show the derivation of each recommended criteria value. For derivation of the recommended Direct Exposure Criteria, Pollutant Mobility Criteria, Groundwater Protection Criteria and Surface Water Protection Criteria for EPH/VPH/APH fractions, the equations and assumptions used in the Remediation Standard Regulations adopted in 1996 were used. For the Volatilization Criteria, the equations and associated exposure assumptions proposed by DEEP in Connecticut's Proposed Revisions Remediation Standard Regulations Volatilization Criteria (DEEP 2003) were used. Similarly, the derivation of the Target Indoor Air Concentrations is based on the DEEP 2003 proposal with some minor modifications, which are discussed in Appendix F.

Once the risk-based values were calculated, the resulting value was adjusted, as necessary, to account for ceiling values, analytical levels or policy considerations.

Figure 1. Criteria Derivation Flow Chart



Ceiling Value

Ceiling values are used as an upper bound value to prevent gross contamination from being overlooked or left in place. The use of these values provides protection of the chemical, physical and biological integrity of the State's environmental resources and recognizes that risk-based evaluations represent the information available at the time the criteria were derived. Should additional new toxicity information become available in the future which indicates that a substance is more toxic than originally thought, the ceiling value provides some measure of protection. Additionally, ceiling values are useful to address other exposure conditions not explicitly included in criteria calculation such as odor thresholds, consideration of multiple pathways of exposure to the same or similar compounds or to complex mixtures.

Table 3. Ceiling Values Used in Criteria Derivation

Criteria Type	Units	Volatile Substances	Semivolatile Substances
Direct Exposure Criteria: Residential	mg/kg	500	1000
Direct Exposure Criteria: Industrial Commercial	mg/kg	1000	2500
Groundwater Protection Criteria	µg/l	1000	1000
Target Indoor Air Concentration	µg/m^3	500	NA
Groundwater Volatilization Criteria	µg/l	50,000	NA

NA: Not Applicable

Adjustments to Criteria Based on Analytical Considerations

Adjustment to risk-based values were made if the reporting levels for the analytical method as indentified in the Connecticut Reasonable Confidence Protocol were greater than the risk-based value. In these cases, the criteria value was adjusted upwards to the analytical reporting limit identified in the Connecticut Reasonable Confidence Protocol method document.

Table 4. Analytical Reporting Levels per CT RCP Method Documents

Method	Aqueous (µg /l)	Soil (mg/kg)	Air (µg /m^3)
EPH	100	20	NA
VPH	100-150	5-10	NA
APH	NA	NA	10-12

Policy Considerations

The proposed criteria have been reviewed to determine if any additional modifications should be included in order to address any additional concerns. Two modifications were identified.

1. Rounding
   The calculated criteria values were rounded to provide a simpler presentation of the criteria, taking into account significant digits while not appreciably altering the level of environmental protection.

2. Consideration of Reference Concentrations
   Recent information on indoor air concentrations of petroleum hydrocarbons is available in a report entitled Technical Updates: Residential Typical Indoor Air Concentrations (MA DEP, 2008). These values have been considered when establishing appropriate Target Indoor Air Concentrations. More detail is provided in Appendix F.

Summary of Recommended Criteria Values

Criteria for EPH/VPH/APH petroleum hydrocarbon fractions as Additional Polluting Substances are recommended for use upon request only, on a site-specific approval basis, for those who wish to utilize those analytical methods for site characterization purposes. Recommended EPH/VPH/APH criteria are summarized in Table 5.

Parties may opt to propose different criteria for EPH/VPH/APH, which includes technical support, for DEEP approval as Additional Polluting Substances.

Table 5. Summary of Remediation Criteria for Petroleum Hydrocarbons Using EPH/VPH/APH Methodologies

Criteria	Units	C_5-C_8 Aliphatics	C_9-C_{12} Aliphatics	C_9-C_{18} Aliphatics	C_{19}-C_{36} Aliphatics	C_9-C_{10} Aromatics	C_{11}-C_{22} Aromatics
Direct Exposure Criteria: Residential	mg/kg	500	500	500	1000	500	500
Direct Exposure Criteria: Industrial/Commercial	mg/kg	1000	1000	1000	2500	1000	1000
Pollutant Mobility Criteria GA	mg/kg	6	15	20	20	5	20
Pollutant Mobility Criteria GB	mg/kg	55	140	140	200	20	30
Groundwater Protection Criteria	µg/l	280	700	700	1000	100	140
Surface Water Protection Criteria	µg/l	200	770	770	530	200	100
Target Indoor Air Concentration: Residential	µg/m^3	130	115	115	Not Volatile	15	15
Target Indoor Air Concentration: Industrial/ Commercial	µg/m^3	330	300	300	Not Volatile	45	45
Groundwater Volatilization Criteria: Residential	µg/l	100	100	100	Not Volatile	450	1,710
Groundwater Volatilization Criteria: Industrial/Commercial	µg/l	215	160	155	Not Volatile	3,300	12,000
Soil Vapor Volatilization Criteria: Residential	mg/m^3	100	90	Not included in APH method	Not Volatile	10	Not included in APH method
Soil Vapor Volatilization Criteria: Residential	ppmV	25	15	Not included in APH method	Not Volatile	2	Not included in APH method
Soil Vapor Volatilization Criteria: Industrial/ Commercial	mg/m^3	460	415	Not included in APH method	Not Volatile	60	Not included in APH method
Soil Vapor Volatilization Criteria: Industrial/ Commercial	ppmV	120	70	Not included in APH method	Not Volatile	15	Not included in APH method

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APPENDICES

Appendix A
Considerations for Use of Analytical Methods

Reporting Analytical Results from VPH/EPH/APH Analysis

For the VPH method, the carbon range analytical results may be adjusted to exclude compounds which are measured during the analytical procedure but which do not belong within the target carbon fractions when considering molecular structure (aliphatic or aromatic). For VPH, this means that:

- the concentration for C_5-C_8 Aliphatic Hydrocarbon range excludes the concentration of the target analytes eluting in that range (Benzene, Toluene and Methyl-tert-butylether).
- the C_9-C_{10} Aliphatic Hydrocarbon range concentration excludes the concentration of the target analytes eluting in that range (Ethylbenzene, the Xylene isomers, and any other C_9-C_{10} aromatics); and
- surrogates and/or internal standards eluting within a target carbon fraction are excluded.

The criteria for carbon ranges for the EPH method are expected to be applied using the unadjusted analytical results except that surrogates and/or internal standards eluting within a target carbon fraction are excluded.

For the APH method, the carbon range analytical results may be adjusted to exclude compounds which are measured during the analytical procedure but which do not belong within the target carbon fractions when considering molecular structure (aliphatic or aromatic). For APH, this means that:

- the concentration for C_5-C_8 Aliphatic Hydrocarbon range excludes the concentration of the target APH analytes eluting in that range.
- the C_9-C_{12} Aliphatic Hydrocarbon range concentration excludes the concentration of the target APH analytes eluting in that range and any other C_9-C_{10} aromatics; and
- surrogates and/or internal standards eluting within a target carbon fractions are excluded.

Use of Leaching Procedures for PMC Compliance Determinations

Restrictions contained in the RSRs, RCSA section 22a-133k-2(c) prohibit the use of the Toxicity Characteristic Leaching Procedure, EPA Method 1311("TCLP") and the Synthetic Precipitation Leaching Procedure, and EPA Method 1312 ("SPLP") for the analysis of Total Petroleum Hydrocarbons ("TPH") by EPA Method 418.1.

The TCLP and SPLP can be used with the ETPH, EPH and VPH methods because these methods do not report TPH using EPA Method 418.1.

Restrictions contained in the RSRS, RCSA section 22a-133k-2(c) prohibit the use of the TCLP and SPLP for the analysis of 1,2 dichlorobenzene, ethyl benzene, toluene and xylenes. These restrictions are proposed to be deleted from the RSRs.

Use of Groundwater Data in Evaluating Pollutant Mobility

Proposed amendments to RSRs Section 22a-133k-c(4) Pollutant Mobility Exemptions include the ability to utilize groundwater data, in specific circumstances, to demonstrate compliance with the pollutant mobility requirements when soil leaching analyses produce results that exceed the RSR pollutant mobility criteria identified in Appendix B.

Appendix B
MA DEP Table of Inhalation Toxicity Values Excerpted from MA DEP 2003

Table 15. Inhalation Toxicity Values for Individual C_9 - C_{18} Fraction Components or Mixtures

Species	Compound/ Fractions Tested	Endpoint	NOAEL/ $LOAEL_{adj}$ (mg/m^3)*	UF Applied	RfC mg/m^3
Rat	Isopropyl benzene	Change in kidney and liver weight	435 ($NOAEL_{adj}$)	1,000 10 – animal to human. 3 – human variability 10 – subchronic to chronic 3 – data deficiency	0.4 (US EPA, 1997a)
Mice	Naphthalene	Respiratory tract toxicity	9.3 ($LOAEL_{adj}$)	3,000 10 – animal to human. 10 – human variability 10 – LOAEL to NOAEL 3 – database deficiency	0.003 (US EPA, 1998)
Rats	**Trimethylbenzene isomers**	**Neurotoxicity**	**22 ($NOAEL_{adj}$)**	**1,000** **10 – animal to human.** **10 – human variability** **10 – subchronic to chronic**	**0.02**
Rats	High flash aromatic naphtha (HFAN) or C_9 mixtures	Weight reduction	1,315 ($LOAEL_{adj}$)	10,000 10 – animal to human. 10 – human variability 3 – LOAEL to NOAEL 3 – database deficiency 10 – subchronic to chronic	0.1
Rats	High flash aromatic naphtha	CNS effects and change in organ weight	160 ($NOAEL_{adj}$)	3,000 10 – animal to human. 10 – human variability 3 – database deficiency 10 – subchronic to chronic	0.05

* Duration adjusted NOAEL/LOAEL

Bolded information is basis for fractional RfC

Appendix C
Direct Exposure Criteria

Table C-1. Residential Direct Exposure Criteria Formulas

For Substances that are non-carcinogenic:

$$DEC_{RB} = \frac{RfD \times HI}{\frac{IRc \times EDc \times EF \times CF}{BWc \times ATc} + \frac{IRa \times EDa \times EF \times CF}{BWa \times ATa}}$$

Variable	Description	Value	Units
ATa	Averaging Time – Adult Non-carcinogen	8760	days
ATc	Averaging Time – Child Non-carcinogen	2190	days
BWa	Body Weight – Adult	70	kg
BWc	Body Weight – Child	15	kg
CF	Conversion Factor	0.000001	kg/mg
DEC_{RB}	Direct Exposure Criteria – Risk-based	chemical specific	mg/kg
EDa	Exposure Duration – Adult	24	years
EDc	Exposure Duration – Child	6	years
EF	Exposure Frequency	365	days/year
HI	Hazard Index	1	unitless
IRa	Ingestion Rate – Adult	100	mg/day
IRc	Ingestion Rate – Child	200	mg/day
RfD	Reference Dose	chemical specific	mg/kg/d

Table C-2. Calculation of Residential Direct Exposure Criteria

Chemical Name	Chemical Type	Toxicity Values		Risk-Based Criteria (mg/kg)	Ceiling Value	Analytical Reporting Level (mg/kg)	Final Criteria (mg/kg)	Criteria Basis
		Type	mg/kg/d					
C_5-C_8 Aliphatic	Volatile	Rfd - Oral	0.04	2,709.67	500	5	500	Ceiling
C_9-C_{12} Aliphatic	Volatile	Rfd - Oral	0.1	6,774.19	500	5	500	Ceiling
C_9-C_{18} Aliphatic	Extractable	Rfd - Oral	0.1	6,774.19	500	20	500	Ceiling
C_{19}-C_{36} Aliphatic	Extractable	Rfd - Oral	2	135,483.87	1,000	20	1,000	Ceiling
C_9-C_{10} Aromatic	Volatile	Rfd - Oral	0.01	677.42	500	5	500	Ceiling
C_{11}-C_{22} Aromatic	Extractable	Rfd - Oral	0.02	1,354.84	500	20	500	Ceiling

Table C-3. Industrial/Commercial Direct Exposure Criteria Formulas

For Substances that are non-carcinogenic:

$$DEC_{RB} = \frac{RfD \times HI \times BW \times ATnc}{IR \times EF \times ED \times CF}$$

Variable	Description	Value	Units
AT	Averaging Time – Carcinogen	25550	days
ATnc	Averaging Time –Non-carcinogen	9125	days
BW	Body Weight – Adult	70	kg
CF	Conversion Factor	0.000001	kg/mg
DEC_{RB}	Direct Exposure Criteria – Risk-based	chemical specific	mg/kg
ED	Exposure Duration	25	years
EF	Exposure Frequency	250	days/year
HI	Hazard Index	1	unitless
IR	Ingestion Rate	50	mg/day
RfD	Reference Dose	chemical specific	mg/kg/d

Table C-4. Calculation of Industrial/Commercial Direct Exposure Criteria

Chemical Name	Chemical Type	Toxicity Values		Risk-Based Criteria (mg/kg)	Ceiling Value (mg/kg)	Analytical Reporting Level (mg/kg)	Final Criteria (mg/kg)	Criteria Basis
		Type	mg/kg/d					
C_5-C_8 Aliphatic	Volatile	Rfd - Oral	0.04	81,760	1,000	5	1,000	Ceiling
C_9-C_{12} Aliphatic	Volatile	Rfd - Oral	0.1	204,400	1,000	5	1,000	Ceiling
C_9-C_{18} Aliphatic	Extractable	Rfd - Oral	0.1	204,400	1,000	20	1,000	Ceiling
C_{19}-C_{36} Aliphatic	Extractable	Rfd - Oral	2	4,088,000	2,500	20	2,500	Ceiling
C_9-C_{10} Aromatic	Volatile	Rfd - Oral	0.01	20,440	1,000	5	1,000	Ceiling
C_{11}-C_{22} Aromatic	Extractable	Rfd - Oral	0.02	40,880	1,000	20	1,000	Ceiling

Appendix D
Pollutant Mobility Criteria

Table D-1. Pollutant Mobility Criteria Formulas

GA PMC (mg/kg) = GWPC x 0.02
GB PMC (mg/kg) = GWPC x 0.2

Table D-2. Calculation of GA Pollutant Mobility Criteria

Chemical Name	Chemical Type	GWPC (µg/L)	Risk-Based GA PMC (mg/kg)	Analytical Reporting Level (mg/kg)	Final Criteria (mg/kg)	Basis
C_5-C_8 Aliphatic	Volatile	280	5.6	5	6	Risk-based
C_9-C_{12} Aliphatic	Volatile	700	14	5	15	Risk-based
C_9-C_{18} Aliphatic	Extractable	700	14	20	20	Analytical Adjustment
C_{19}-C_{36} Aliphatic	Extractable	1,000	20	20	20	Risk-based
C_9-C_{10} Aromatic	Volatile	100	2	5	5	Analytical Adjustment
C_{11}-C_{22} Aromatic	Extractable	140	2.8	20	20	Analytical Adjustment

Table D-3. Calculation of GB Pollutant Mobility Criteria

Chemical Name	Chemical Type	GWPC (µg/L)	Risk-Based GB PMC (mg/kg)	Analytical Reporting Level (mg/kg)	Final Criteria (mg/kg)	Basis
C_5-C_8 Aliphatic	Volatile	280	56	5	55	Risk-based
C_9-C_{12} Aliphatic	Volatile	700	140	5	140	Risk-based
C_9-C_{18} Aliphatic	Extractable	700	140	20	140	Risk-based
C_{19}-C_{36} Aliphatic	Extractable	1,000	200	20	200	Risk-based
C_9-C_{10} Aromatic	Volatile	150	20	5	20	Risk-based
C_{11}-C_{22} Aromatic	Extractable	140	28	20	30	Risk-based

Appendix E
Groundwater Protection Criteria

Table E-1. Groundwater Protection Criteria Formulas

For Substances that are non-carcinogenic:

GWPC (ug/L) = (Rfd x HI) x ((BW x AT x SA) / (IR x EF x ED x CF))

Variable	Description	Value	Units
AT	Averaging Time	25550	days
BW	Body Weight	70	kg
CF	Conversion Factor	0.001	mg/µg
ED	Exposure Duration	70	years
EF	Exposure Frequency	365	days/year
HI	Hazard Index	1	unitless
IR	Ingestion Rate	2	liter/day
RfD	Reference Dose	chemical specific	mg/kg/d
SA	Source Allocation	0.2	unitless

Table E-2. Calculation of Groundwater Protection Criteria

Chemical Name	Chemical Type	Toxicity Values		Risk-Based Criteria (µg/L)	Ceiling Value (µg/L)	Analytical Reporting Level (µg/L)	Final Criteria (µg/L)	Basis
		Type	mg/kg/d					
C_5-C_8 Aliphatic	Volatile	Rfd - Oral	0.04	280	1,000	100	280	Risk-based
C_9-C_{12} Aliphatic	Volatile	Rfd - Oral	0.1	700	1,000	100	700	Risk-based
C_9-C_{18} Aliphatic	Extractable	Rfd - Oral	0.1	700	1,000	100	700	Risk-based
C_{19}-C_{36} Aliphatic	Extractable	Rfd - Oral	2	14,000	1,000	100	1,000	Ceiling
C_9-C_{10} Aromatic	Volatile	Rfd - Oral	0.01	70	1,000	100	100	Analytical Adjustment
C_{11}-C_{22} Aromatic	Extractable	Rfd - Oral	0.02	140	1,000	100	140	Risk-based

Appendix F
Target Indoor Air Concentrations

The proposal to revise the Volatilization Criteria made by the Department in 2003 included changes to some of the exposure assumptions used in the derivation of the Target Indoor Air Concentrations, establishment of a ceiling value, as well as a recognition of the increased exposure and susceptibility of children to carcinogens.

Exposure Assumptions

In 2003, the Department proposed to reduce the inhalation rate for use in Industrial/Commercial settings from 20 m^3/day to 10 m^3/day in recognition of the reduced exposure period associated with time at the workplace. This recommendation has been incorporated into the criteria derived herein.

For the calculation of the Residential Target Indoor Air Concentration, the Department did not propose any changes to the exposure assumptions in 2003. However, for the current calculations, exposure assumption represented in the Exposure Frequency variable has been adjusted from 350 days/year to 365 days/year, consistent with the residential exposure assumptions included in the Direct Exposure Criteria as well as the assumptions used in the derivation of the Groundwater Protection Criteria.

Ceiling Concentration

The proposal in 2003 included a ceiling concentration of 500 ug/m^3 for establishing Target Indoor Air Concentrations. This ceiling concentration was used in derivation of risk-based Target Indoor Air Concentrations.

Increased Exposure of Children

Children are recognized as a sensitive population. In general, children have a greater rate of exposure to contaminants than do adults because children drink more water, ingest more soil and inhale more air per body weight than adults. Also, children are more sensitive to the toxic effects of certain types of chemicals. In the 2003 proposed changes to the Volatilization Criteria, the Department recognized this factor and included adjustments, applied to the toxicity values, to recognize children's increased inhalation rate (a 2-fold adjustment factor) and a second factor to account for children's increased sensitivity to genotoxic carcinogens.

For noncarcinogenic substances, the use of the Reference Dose without any modification for children remains appropriate in the general case. Since the criteria derived for EPH and VPH hydrocarbon fractions are developed using non-cancer toxicity endpoints, the adjustment used in 2003 for genotoxic carcinogens were not used in the current criteria derivation. A Children's Vulnerability Factor (CVF), however, was incorporated to reflect the differential exposure rate for inhalation exposures when accounting for the differences between children and adults. In

2003, a 2-fold adjustment factor was used and applied to the toxicity value. In the current process, this factor was recalculated and reduced to 1.75 and was incorporated into the equation as a separate variable to more clearly state the child-specific consideration.

Calculation of the Children Vulnerability Factor (CVF) for Inhalation Exposures to Non-Carcinogenic Substances

Exposure Period for Non-carcinogens:

For non-carcinogens, there is no uniform window of increased vulnerability for children, as this will vary depending upon the chemical's toxic mechanism of action. Instead, the risk-based calculations rely upon USEPA's determination of the Minimal Chronic Exposure Period as 10% of a person's lifespan or 7 years (USEPA, 2002A). This Minimal Chronic Exposure Period is taken as the first 7 years of life to ensure that children's higher exposure rates are captured in the regulations. Current residential Target Indoor Air Concentrations assumes a 6 year exposure period for children. No change is proposed to this exposure period since it closely approximates the Minimal Chronic Exposure Period recommended by EPA.

Calculating the CVF for Inhalation Exposures:

Exposure Factors for Children during the Minimal Chronic Exposure Period:

Inhalation rate for 0-7 year old children: 8 m^3/d
Body weight for 0-7 year old children: 16 kg
Ratio of Inhalation Rate to Body Weight = 0.5

Exposure Factors for Adults:

Inhalation rate for Adults: 20 m^3/d
Body weight for Adults: 70 kg
Ratio of Inhalation Rate to Body Weight = 0.286

CVF for Noncarcinogens during inhalation exposures is calculated as the ratio of child/adult exposure.

CVF = 0.5/0.286 = 1.75

Reference Conditions

Risk-based Target Indoor Air Concentrations were compared with measured indoor air concentrations of petroleum hydrocarbons. If the risk-based Target Indoor Air Concentrations were less than the observed reference indoor air concentrations, then the Target Indoor Air Concentrations were adjusted up to the reference condition.

The reference conditions for indoor air concentrations were obtained from a report on typical concentrations of various contaminants found in indoor air published by MADEP in December 2008 in a publication entitled Residential Typical Indoor Air Concentrations. This document summarized the results of various studies and presents a table of observed contaminant concentrations in indoor air and provides the 50^{th}, 75^{th} and 90^{th} percentile values. The tables include values for the following petroleum hydrocarbon fractions: C_5-C_8 Aliphatics, C_9-C_{12} Aliphatics and C_9-C_{10} Aromatics. The 75^{th} percentile values were used as reference conditions for residential indoor air. Since similar studies were not available for indoor air in an industrial/commercial setting, the 90^{th} percentile value from the residential study was used to represent potential reference conditions in an industrial/commercial setting. Also, when data was unavailable for several fractions, reference conditions from a related fraction was used. Specifically, the values for C_9-C_{12} Aliphatics was used to represent C_9-C_{18} Aliphatics, and the value for C_9-C_{10} Aromatics was used to represent C_{11}-C_{22} Aromatics. In the case where the published reference condition was reported as non-detect, the reporting level from the appropriate RCP method was used as the detection limit.

Table F-1. Residential Target Indoor Air Concentration Formulas

For Substances that are Non-carcinogenic:

TAC = (HQ x x RfDi x AT x CF) / ((x CVFnc x EF x ED)

Where:

Variable	Description	Value	Units
AT	Averaging Time – Non-carcinogen	10950	days
BW	Body Weight	70	kg
CF	Conversion Factor	1000	ug/mg
ED	Exposure Duration	30	years
EF	Exposure Frequency	365	days/year
HQ	Hazard Quotient	1	unitless
IRair	Inhalation Rate – Air	20	$m^{3/}$day
RfDC	Reference Dose – Inhalation	chemical specific	mg/m^3
CVFnc	Children's Vulnerability Factor – non-carcinogen	1.75	unitless

Table F-2. Calculation of Residential Target Indoor Air Concentrations

Chemical Name	Toxicity Values		Mutagenicity	Risk-Based Criteria (µg/m³)	Reference Conditions (µg/m³)	Ceiling Value (µg/m³)	Final Criteria (µg/m³)
	Type	mg/m³					
C_5-C_8 Aliphatic	RfC - Inhalation	0.2	Not mutagenic	114	130	500	130
C_9-C_{12} Aliphatic	RfC - Inhalation	0.2	Not mutagenic	114	110	500	115
C_9-C_{18} Aliphatic	RfC - Inhalation	0.2	Not mutagenic	114	110	500	115
C_{19}-C_{36} Aliphatic	RfC - Inhalation		Not Volatile				
C_9-C_{10} Aromatic	RfC - Inhalation	0.025	Not mutagenic	14	10	500	15
C_{11}-C_{22} Aromatic	RfC - Inhalation	0.025	Not mutagenic	14	10	500	15

Table F-3: Industrial/Commercial Target Indoor Air Concentration Formulas

For Substances that are Non-carcinogenic:

TAC ($\mu g/m^3$)= (HQ x RfC x AT x CF) / ((EF x ED)

Variable	Description	Value	Units
AT	Averaging Time – Non-carcinogen	9125	days
CF	Conversion Factor	1000	µg/mg
ED	Exposure Duration	25	years
EF	Exposure Frequency	365	days/year
HQ	Hazard Quotient	1	unitless
RfC	Reference Dose – Inhalation	chemical specific	mg/m^3

Table F-4. Calculation of Industrial/Commercial Target Indoor Air Concentration

Chemical Name	Toxicity Values		Mutagenicity	Risk-Based Criteria (µg/m³)	Reference Conditions (µg/m³)	Ceiling Value (µg/m³)	Final Criteria (µg/m³)
	Type	mg/m³					
C_5-C_8 Aliphatic	RfC - Inhalation	0.2	Not mutagenic	292	330	500	330
C_9-C_{12} Aliphatic	RfC - Inhalation	0.2	Not mutagenic	292	220	500	300
C_9-C_{18} Aliphatic	RfC - Inhalation	0.2	Not mutagenic	292	220	500	300
C_{19}-C_{36} Aliphatic	RfC - Inhalation		Not Volatile				
C_9-C_{10} Aromatic	RfC - Inhalation	0.025	Not mutagenic	36.5	44	500	45
C_{11}-C_{22} Aromatic	RfC - Inhalation	0.025	Not mutagenic	36.5	44	500	45

Appendix G
Volatilization Criteria

Table G-1. Volatilization Criteria Formulas

For Ground Water Volatilization Criteria:

$GWVC\ (ug/L) = TAC / (1000\ L/m^3 \times \alpha \times H)$

For Soil Vapor Volatilization Criteria:

$SVVC\ (mg/m^3) = TAC / (1000\ ug/mg \times \alpha)$

$SVVC\ (ppm) = SVVC\ (mg/m^3) \times 24.45 / Molecular\ Weight$

Where:

$$\alpha = (A \times e^B) / (e^B + A + (A/C) \times (e^B - 1))$$

Where:

$$A = (D^{eff}_T \times A_B) / (Q_B \times L_T)\ \textbf{\textit{or}}\ (D^{eff}_T) / (E_B \times (V_B/A_B) \times L_T)$$

$$B = (Q_{soil} \times L_{crack}) / (D^{eff}_{crack} \times \eta \times A_B)\ \textbf{\textit{or}}\ ((Q_{soil}/Q_b) \times E_B \times (V_B/A_B) \times L_{crack}) / (D^{eff}_{crack} \times \eta)$$

$$C = (Q_{soil}/Q_b)$$

Where:

$$D^{eff}_T = L_T / ((L_{vadose}/D^{eff}_{vadose}) + (L_{cap}/D^{eff}_{cap})$$

$$D^{eff}_{crack} = D^{air} \times (\theta_{V\text{-}crack}^{3.33}/\theta_{T\text{-}crack}^{2}) + (D^{water}/H) \times (\theta_{m\text{-}crack}^{3.33}/\theta_{T\text{-}crack}^{2})$$

Where:

$$D^{eff}_{vadose} = D^{air} \times (\theta_{V\text{-}vadose}^{3.33} / \theta_{T\text{-}vadose}^{2}) + (D^{water}/H) \times (\theta_{m\text{-}vadose}^{3.33} / \theta_{T\text{-}vadose}^{2})$$

$$D^{eff}_{cap} = D^{air} \times (\theta_{V\text{-}cap}^{3.33} / \theta_{T\text{-}cap}^{2}) + (D^{water}/H) \times (\theta_{m\text{-}cap}^{3.33} / \theta_{T\text{-}cap}^{2})$$

Where:

Variable	Description	Value	Units
GWVC	Ground Water Volatilization Criteria	calculated	ug/kg
TAC	Target Indoor Air Concentration	Appendix D	ug/m^3
α	Attenuation Factor for Diffusion and Advection	calculated	unitless
SVVC	Soil Vapor Volatilization Criteria	calculated	mg/m^3
24.45	Molar Volume (at standard conditions)	24.45	liters
D^{eff}_T	Total Effective Diffusion	calculated	cm^2/s
D^{eff}_{crack}	Effective Diffusion Through Foundation Cracks	calculated	cm^2/s
D^{eff}_{cap}	Effective Diffusion Through Capillary Fringe	calculated	cm^2/s
D^{eff}_{vadose}	Effective Diffusion Through Vadose Zone	calculated	cm^2/s
H	Henry's Law Constant	chemical specific	unitless
$\theta_{m\text{-}vadose}$	Volumetric Moisture Content in Vadose Zone	calculated	unitless
$\theta_{T\text{-}vadose}$	Total Porosity in Vadose Zone	calculated	unitless
$\theta_{m\text{-}crack}$	Volumetric Moisture Content in Cracks	calculated	unitless
$\theta_{T\text{-}crack}$	Total Porosity in Crack	calculated	unitless
$\theta_{m\text{-}cap}$	Volumetric Moisture Content in Cracks in Capillary Fringe	calculated	unitless
$\theta_{T\text{-}cap}$	Total Porosity in Capillary Fringe	calculated	unitless
D^{air}	Molecular Diffusion Coefficient in Air	chemical specific	m^2/d
D^{water}	Molecular Diffusion Coefficient in Water	chemical specific	m^2/d
η	Fraction of Enclosed Space Area Open for Vapor Intrusion	calculated	m^2/d
A_B	Surface Area of the Enclosed Space in Contact with Soil	calculated	m^2
V_B	Enclosed Space Volume	calculated	m^3
E_B	Enclosed Space Air Exchange Rate	calculated	1/day
L_T	Depth from foundation to source	calculated	m
L_{cap}	Thickness of Capillary Fringe	calculated	m
L_{crack}	Foundation Thickness	calculated	m
Q_B	Enclosed Space Volumetric Air Flow Rate	calculated	m^3/d
$\theta_{v\text{-}vadose}$	Volumetric Vapor Content in Vadose Zone	calculated	unitless
$\theta_{V\text{-}crack}$	Volumetric Vapor Content in Cracks	calculated	unitless
$\theta_{V\text{-}cap}$	Volumetric Vapor Constant in Capillary Fringe	calculated	unitless

Table G-2. Definition of Variables

Variable	Definition	Units
H	Chemical Specific Henry's Law constant	$\mu g/m^3$-vapor / $\mu g/m^3$-H_2O
$\theta_{m\text{-}vadose}$	Volumetric Moisture Content in Vadose Zone	m^3-H_2O / m^3-soil
$\theta_{T\text{-}vadose}$	Total Porosity in Vadose Zone	m^3-voids / m^3-soil
$\theta_{m\text{-}crack}$	Volumetric Moisture Content in Cracks	m^3-H_2O / m^3-soil
$\theta_{T\text{-}crack}$	Total Porosity in Cracks	m^3-voids / m^3-soil
$\theta_{m\text{-}cap}$	Volumetric Moisture Content in Cracks in Capillary Fringe	m^3-H_2O / m^3-soil
$\theta_{T\text{-}cap}$	Total Porosity in Capillary Fringe	m^3-voids / m^3-soil
D^{air}	Chemical Specific Molecular Diffusion Coefficient in Air	m^2 / d
D^{water}	Chemical Specific Molecular Diffusion Coefficient in Water	m^2 / d
K	Soil Permeability (near foundation) to Air Flow	m^2
ΔP	Indoor-Outdoor Air Pressure Difference	g / ms^2
X_{crack}	Total Length of Cracks through which Soil Gas Vapors are Flowing	m
μ	Viscosity of Air	g / ms
Z_{crack}	Crack Opening Depth Below Grade	m
η	Fraction of Enclosed Space Area Open for Vapor Intrusion	m^2 / m^2
A_B	Surface Area of the Enclosed Space in Contact with Soil	m^2
V_B	Enclosed Space Volume	m^3
E_B	Enclosed Space Air Exchange Rate	1/d
L_T	Depth from Foundation to Source	m
L_{cap}	Thickness of Capillary Fringe	m
L_{crack}	Foundation Thickness	m

Table G-3. Calculated Variables

Variable	Definition	Calculation	Units
V_B/A_B	Ratio of Enclosed Space Volume to Exposed Surface Area		m
Q_B	Enclosed Space Volumetric Air Flow Rate	$= V_B E_B$	m^3 / d
R_{crack}	Effective Crack Radius or Width	$= \eta A_B / X_{crack}$	m
$\theta_{V\text{-}vadose}$	Volumetric Vapor Content in Vadose Zone	$= \theta_{T\text{-}vadose} - \theta_{m\text{-}vadose}$	m^3-vapor / m^3-soil
$\theta_{V\text{-}crack}$	Volumetric Vapor Content in Cracks	$= \theta_{T\text{-}crack} - \theta_{m\text{-}crack}$	m^3-vapor / m^3-soil
$\theta_{V\text{-}cap}$	Volumetric Vapor Content in Capillary Fringe	$= \theta_{T\text{-}cap} - \theta_{m\text{-}cap}$	m^3-vapor / m^3-soil
Q_{soil}	Pressure Driven Soil Gas Flow Rate from the subsurface into the enclosed space	$= (2\pi k \Delta P X_{crack}) / [\mu \ln(2Z_{crack}/R_{crack})]$	m^3 / d
Q_{soil}/Q_B	Ratio of Soil Gas Intrusion Rate to Building Ventilation Rate		unitless
D^{water}/D^{air}	Ratio of Molecular Diffusion in water to air		unitless
L_{vadose}	Thickness of Vadose Zone	$= L_T - L_{cap}$	m

Table G-4. Default Input Values

Variable	Units	Typical Value Range [(1)]	Notes	Res GWVC	I/C GWVC	Res SVVC	I/C SVVC
H	µg/m^3-vapor / µg/m^3-H_2O	0.01 - 1.0	For most aromatic & chlorinated solvents	---	---	---	---
$\theta_{m\text{-}vadose}$	m^3-H_2O / m^3-soil		ASTM default value. Typical for sand.	0.12	0.12	0.12	0.12
$\theta_{T\text{-}vadose}$	m^3-voids / m^3-soil		ASTM default value. Typical for sand.	0.38	0.38	0.38	0.38
$\theta_{m\text{-}crack}$	m^3-H_2O / m^3-soil		ASTM default value. Typical for sand.	0.12	0.12	0.12	0.12
$\theta_{T\text{-}crack}$	m^3-voids / m^3-soil		ASTM default value. Typical for sand.	0.38	0.38	0.38	0.38
$\theta_{m\text{-}cap}$	m^3-H_2O / m^3-soil		ASTM default value. Typical for sand.	0.342	0.342	0.342	0.342
$\theta_{T\text{-}cap}$	m^3-voids / m^3-soil		ASTM default value. Typical for sand.	0.38	0.38	0.38	0.38
D^{air}	M^2 / d	0.1 - 1	For most chemicals	7.26E-01	7.26E-01	7.26E-01	7.26E-01
D^{water}	M^2 / d			8.64E-05	8.64E-05	8.64E-05	8.64E-05
k	m^2	1E-6 - 1E-12					
ΔP	g / ms^2	0 - 200	or 0 to 20 Pascals				
X_{crack}	m						
µ	g / ms						
Z_{crack}	m						
η	m^2 / m^2	0.0005 - 0.005	ASTM default value. 0.01 for worst-case scenario.	0.01	0.01	0.01	0.01
A_B	m^2						
V_B	m^3	147 - 672	Range from USDOE (1995)				
E_B	1/d	4.8 - 24	ASTM default values. 12 for Residential scenario and 19.9 for Industrial/Commercial scenario.	12	19.9	12	19.9
L_T	m	0.01 - 50	ASTM default values. 3 for Groundwater criteria and 1 for Soil Vapor criteria.	3	3	1	1
L_{cap}	m		ASTM default values. 0.05 for Groundwater criteria and 0 for Soil Vapor criteria.	0.05	0.05	0	0
L_{crack}	m	0.15 - 0.5	ASTM default value.	0.15	0.15	0.15	0.15

Variable	Units	Typical Value Range [1]	Notes	Res GWVC	I/C GWVC	Res SVVC	I/C SVVC
V_B/A_B	m	2 - 3	ASTM default values. 2 for Residential scenario and 3 for Industrial/Commercial scenario.	2	3	2	3
Q_B	m^3 / d						
R_{crack}	m						
$\theta_{V\text{-}vadose}$	m^3-vapor / m^3-soil		ASTM default value. Typical for sand.	0.26	0.26	0.26	0.26
$\theta_{V\text{-}crack}$	m^3-vapor / m^3-soil		ASTM default value. Typical for sand.	0.26	0.26	0.26	0.26
$\theta_{V\text{-}cap}$	m^3-vapor / m^3-soil		ASTM default value. Typical for sand.	0.038	0.038	0.038	0.038
Q_{soil}	m^3 / d						
Q_{soil}/Q_B	unitless	0.0001 – 0.05	EPA Vapor Intrusion Guidance default value.	0.003	0.003	0.003	0.003
D^{water}/D^{air}	unitless	~ 1E-4		1.19E-04	1.19E-04	1.19E-04	1.19E-04
L_{vadose}	m		ASTM default value. 2.95 for Groundwater criteria and 1 for Soil Vapor criteria.	2.95	2.95	1	1

[1] Johnson, (2002), *Identification of Critical Parameters for the Johnson and Ettinger (1991) Vapor Intrusion Model*, API Bulletin #17, May.

Table G-5. Calculation of Residential Groundwater Volatilization Criteria

Chemical Name	Toxicity Values		Risk-Based Criteria (µg/L)	Ceiling Value (µg/L)	Analytical Reporting Level (µg/L)	Final Criteria (µg/L)	Basis
	Type	mg/m^3					
C_5-C_8 Aliphatic	RfC - Inhalation	0.2	34.53	50,000	100	100	Analytical Adjustment
C_9-C_{12} Aliphatic	RfC - Inhalation	0.2	25.39	50,000	100	100	Analytical Adjustment
C_9-C_{18} Aliphatic	RfC - Inhalation	0.2	23.92	50,000	100	100	Analytical Adjustment
C_{19}-C_{36} Aliphatic	RfC - Inhalation	Not Volatile		50,000	100		
C_9-C_{10} Aromatic	RfC - Inhalation	0.025	449.09	50,000	100	450	Risk-based
C_{11}-C_{22} Aromatic	RfC - Inhalation	0.025	1,709.43	50,000	100	1,710	Risk-based

Table G-6. Calculation of Industrial/Commercial Groundwater Volatilization Criteria

Chemical Name	Toxicity Values		Risk-Based Criteria (µg/L)	Ceiling Value (µg/L)	Analytical Reporting Level (µg/L)	Final Criteria (µg/L)	Basis
	Type	mg/m^3					
C_5-C_8 Aliphatic	RfC - Inhalation	0.2	215.00	50,000	100	215	Risk-based
C_9-C_{12} Aliphatic	RfC - Inhalation	0.2	162.46	50,000	100	160	Risk-based
C_9-C_{18} Aliphatic	RfC - Inhalation	0.2	153.07	50,000	100	155	Risk-based
C_{19}-C_{36} Aliphatic	RfC - Inhalation	NA		50,000	100		
C_9-C_{10} Aromatic	RfC - Inhalation	0.025	3,283.71	50,000	100	3,300	Risk-based
C_{11}-C_{22} Aromatic	RfC - Inhalation	0.025	12,012.89	50,000	100	12,000	Risk-based

Table G-7. Calculation of Residential Soil Vapor Volatilization Criteria

Chemical Name	Toxicity Values		Risk-Based Criteria mg/m³	Analytical Reporting Level mg/m³	Final Criteria		Basis
	Type	mg/m³			mg/m³	ppb	
C5-8 Aliphatic	RfC - Inhalation	0.2	98.42	0.01	100	25	Risk-based
C9-12 Aliphatic	RfC - Inhalation	0.2	87.05	0.01	90	15	Risk-based
C9-18 Aliphatic	RfC - Inhalation	0.2	87.05				Analytical Method Insufficient
C19-36 Aliphatic	RfC - Inhalation	NA					
C9-10 Aromatic	RfC - Inhalation	0.005	11.35	0.01	10	2	Risk-based
C11-22 Aromatic	RfC - Inhalation	0.003	11.35				Analytical Method Insufficient

Table G-8. Calculation of Industrial/Commercial Soil Vapor Volatilization Criteria

Chemical Name	Toxicity Values		Risk-Based Criteria mg/m^3	Analytical Reporting Level mg/m^3	Final Criteria		Basis
	Type	mg/m^3			mg/m^3	ppmV	
C5-8 Aliphatic	RfC - Inhalation	0.2	457.86	0.01	460	120	Risk-based
C9-12 Aliphatic	RfC - Inhalation	0.2	416.23	0.01	415	70	Risk-based
C9-18 Aliphatic	RfC - Inhalation	0.2	416.23				Analytical Method Insufficient
C19-36 Aliphatic	RfC - Inhalation	NA					
C9-10 Aromatic	RfC - Inhalation	0.005	62.43	0.01	60	15	Risk-based
C11-22 Aromatic	RfC - Inhalation	0.003	62.43				Analytical Method Insufficient

Appendix H
Surface Water Protection Criteria

Surface Water Protection Criteria are established using water quality criteria for surface water bodies, including Ambient Water Quality Criteria for the Protection of Human Health, which assumes that fish may be caught and consumed from the surface water body, and also Ambient Water Quality Criteria for the Protection of Aquatic Life from chronic toxic impacts. These values are established in accordance with EPA procedures and consistent with the Connecticut Water Quality Standards.

Currently, the Connecticut Water Quality Standards (DEEP 2011) and the Nationally Recommended Ambient Water Quality Criteria identified by EPA do not have aquatic life criteria for petroleum hydrocarbons. In order to develop Surface Water Protection Criteria, water quality criteria were calculated using the Tier 2 procedures established in the Water Quality Guidance for the Great Lakes System (USEPA 1995). Tier 2 criteria were either derived by CTDEP using the USEPA 1995 protocols or were obtained from other states that had used this protocol (GLI 2.11). Such criteria derived by CTDEP utilized aquatic toxicity information available from the USEPA EcoTox Database.

The proposed Surface Water Protection Criteria are established as chronic aquatic life water quality benchmark multiplied by a default dilution factor of 10.

Table H-1. Calculation of Surface Water Protection Criteria

Chemical Name	Surrogate	Chronic Aquatic Life Criteria (ug/L)	Chronic Aquatic Life Criteria Basis	Risk-Based Surface Water Protection Criteria (ug/L)	Analytical Reporting Level (ug/L)	Final Criteria (ug/L)	Surface Water Protection Criteria Basis
C5-8 Aliphatic	Hexane	20	CT Tier 2	200	100	200	Risk-based
C9-12 Aliphatic	Decane	77	CT Tier 2	770	100	770	Risk-based
C9-18 Aliphatic	Decane	77	CT Tier 2	770	100	770	Risk-based
C19-36 Aliphatic	Cyclododecane	53	CT Tier 2	530	100	530	Risk-based
C9-10 Aromatic	1,2,4 Trimethyl Benzene 1,3,5 Trimethyl Benzene	1,2,4 Trimethyl Benzene: 15 1,3,5 Trimethyl Benzene: 26 Average: 20	GLI 2.11	200	100	200	Risk-based
C11-22 Aromatic	Acenaphthene Anthracene Fluoranthene Fluorene Phenanthrene Pyrene	Acenaphthene: 15 Anthracene: 0.0253 Fluoranthene: 0.914 Fluorene: 3.23 Phenanthrene: 1.4 Pyrene: 7.78 Average: 4.7	GLI 2.11	47	100	100	Analytical Adjustment

GLI 2.11: Great Lakes Initiative Toxicity Data Clearinghouse V 2.11

Table H-2. Calculation of Connecticut Tier 2 Chronic Aquatic Life Criteria

Calculations of Connecticut Tier 2 Chronic Aquatic Life Criteria			
	Hexane	**Decane**	**Cyclododecane**
Lowest Genus Mean Acute Value (ug/L)	2500	18000	21000
Number of Data Requirements Satisfied	4	2	1
Secondary Acute Factor	7	13	21.9
Secondary Acute Value (ug/L)	357	1385	959
Acute to Chronic Ratio	18	18	18
Acute Aquatic Life Water Quality Criteria (ug/l)	**178**	**692**	**479**
Chronic Aquatic Life Water Quality Criteria (ug/l)	**20**	**77**	**53**

Table H-3. Data Used to Derive Aquatic Life Criteria for Hexane

Derivation of Freshwater Aquatic Life Criteria				
Chemical	**Hexane**			
CASRN	110543			
Date of EcoTox Query	August 17, 2011			
Data Requirements: Data from 8 Different Families Including:				
1. Family Salmonidae in the Class Ostreichthyes				
Organism	Test Type	Result (ug/L)	Species Mean Acute Value	Genus Mean Acute Value
2. One Other Warm Water Species in Class Ostreichthyes which is Commercially or Recreationally Important				
Organism	Test Type	Result (ug/L)	Species Mean Acute Value	Genus Mean Acute Value
Pimephales promelas	96 hr LC50	2500	2500	2500
3. Third Family in Phylum Chordata (e.g. fish, amphibian)				
Organism	Test Type	Result (ug/L)	Species Mean Acute Value	Genus Mean Acute Value
4. Planktonic Crustacean (e.g. cladoceran, copepod)				
Organism	Test Type	Result (ug/L)	Species Mean Acute Value	Genus Mean Acute Value
Daphnia magna	48 hr EC50	3878	3878	3878
Cyclops viridis	48 hr EC50	732500	732500	732500
5. Benthic Crustacean (e.g. ostracod, isopod, amphipod)				
Organism	Test Type	Result (ug/L)	Species Mean Acute Value	Genus Mean Acute Value
6. Insect (e.g. mayfly, dragonfly, stonefly, caddisfly, mosquito, midge)				
Organism	Test Type	Result (ug/L)	Species Mean Acute Value	Genus Mean Acute Value
Chironimidae	96 hr LC50	595000	595000	595000
7. Family in a phylum other than Arthropoda or Chordata (e.g. Rotifera, Annelida, Mollusca)				
Organism	Test Type	Result (ug/L)	Species Mean Acute Value	Genus Mean Acute Value
8. Family in Any Order of Insect or Any Phylum not Already Represented				
Organism	Test Type	Result (ug/L)	Species Mean Acute Value	Genus Mean Acute Value
Branchiura sowerbyi	96 hr LC50	3286500	3286500	3286500

Table H-4. Data Used to Derive Aquatic Life Criteria for Decane

Derivation of Freshwater Aquatic Life Criteria				
Chemical	**Decane**			
CASRN	124185			
Date of EcoTox Query	August 17, 2011			
Data Requirements: Data from 8 Different Families Including:				
1. Family Salmonidae in the Class Ostreichthyes				
Organism	Test Type	Result (ug/L)	Species Mean Acute Value	Genus Mean Acute Value
2. One Other Warm Water Species in Class Ostreichthyes which is Commercially or Recreationally Important				
Organism	Test Type	Result (ug/L)	Species Mean Acute Value	Genus Mean Acute Value
Lepomis macrochirus	96 hr LC50	530000	530000	530000
3. Third Family in Phylum Chordata (e.g. fish, amphibian)				
Organism	Test Type	Result (ug/L)	Species Mean Acute Value	Genus Mean Acute Value
4. Planktonic Crustacean (e.g. cladoceran, copepod)				
Organism	Test Type	Result (ug/L)	Species Mean Acute Value	Genus Mean Acute Value
Daphnia magna	48 hr EC50	18000	18000	18000
5. Benthic Crustacean (e.g. ostracod, isopod, amphipod)				
Organism	Test Type	Result (ug/L)	Species Mean Acute Value	Genus Mean Acute Value
6. Insect (e.g. mayfly, dragonfly, stonefly, caddisfly, mosquito, midge)				
Organism	Test Type	Result (ug/L)	Species Mean Acute Value	Genus Mean Acute Value
7. Family in a phylum other than Arthropoda or Chordata (e.g. Rotifera, Annelida, Mollusca)				
Organism	Test Type	Result (ug/L)	Species Mean Acute Value	Genus Mean Acute Value
8. Family in Any Order of Insect or Any Phylum not Already Represented				
Organism	Test Type	Result (ug/L)	Species Mean Acute Value	Genus Mean Acute Value

Table H-5. Data Used to Derive Aquatic Life Criteria for Cyclododecane

Derivation of Freshwater Aquatic Life Criteria				
Chemical	**Cyclododecane**			
CASRN	294622			
Date of EcoTox Query	August 17, 2011			
Data Requirements: Data from 8 Different Families Including:				
1. Family Salmonidae in the Class Ostreichthyes				
Organism	Test Type	Result (ug/L)	Species Mean Acute Value	Genus Mean Acute Value
2. One Other Warm Water Species in Class Ostreichthyes which is Commercially or Recreationally Important				
Organism	Test Type	Result (ug/L)	Species Mean Acute Value	Genus Mean Acute Value
3. Third Family in Phylum Chordata (e.g. fish, amphibian)				
Organism	Test Type	Result (ug/L)	Species Mean Acute Value	Genus Mean Acute Value
4. Planktonic Crustacean (e.g. cladoceran, copepod)				
Organism	Test Type	Result (ug/L)	Species Mean Acute Value	Genus Mean Acute Value
Daphnia pulex	48 hr EC50	21000	21000	21000
5. Benthic Crustacean (e.g. ostracod, isopod, amphipod)				
Organism	Test Type	Result (ug/L)	Species Mean Acute Value	Genus Mean Acute Value
6. Insect (e.g. mayfly, dragonfly, stonefly, caddisfly, mosquito, midge)				
Organism	Test Type	Result (ug/L)	Species Mean Acute Value	Genus Mean Acute Value
7. Family in a phylum other than Arthropoda or Chordata (e.g. Rotifera, Annelida, Mollusca)				
Organism	Test Type	Result (ug/L)	Species Mean Acute Value	Genus Mean Acute Value
8. Family in Any Order of Insect or Any Phylum not Already Represented				
Organism	Test Type	Result (ug/L)	Species Mean Acute Value	Genus Mean Acute Value