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Risk-Based Remediation Criteria Calculators: Additional Polluting Substances and Alternative Exposure Scenario - Instructions and Supporting Documentation

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I. Included Tools

i. **Additional Polluting Substances (APS) Criteria Calculator** - The Release-Based Cleanup Regulations (RBCRs), contain numeric cleanup standards for 88 substances (chemicals). For contaminants (chemicals) not included in the RBCRs, you can use the APS Criteria Calculator to determine the numerical cleanup standards for the various criteria included in the RBCRs.

ii. **Alternative Exposure Scenario Criteria Calculator** – This tool calculates soil direct exposure criteria for either exposure to both adults and children or exposures only to adults. This calculator allows the user to create alternative exposure scenarios not currently included in the RBCRs.

II. Before Starting

Gather the following information before using the calculators.

i. **Chemical Name (Substance), the Chemical Abstracts Service Registry Number (CASRN), and Physical Constants** – The CompTox Dashboard is hosted by the federal Environmental Protection Agency (EPA) and provides comprehensive information about individual chemicals including the physical properties, information on fate and transport, as well as toxicity information on chemicals. To use the EPA CompTox Dashboard, enter the substance (chemical name) into the search bar. A list of chemicals will appear. Please select the appropriate chemical from the list.

The following physical constants are needed for criteria calculations:

- Molecular weight (g/mol) [Volatilization Criteria]
- Henry's Law Constant (atm-m^3/mol) [Volatilization Criteria]

ii. **Type of Chemical** – Choices: Inorganic, Pesticide, Semivolatile Organic Chemicals (SVOC), Volatile Organic Chemicals (VOC), Per- and Polyfluorinated Alkyl Substances (PFAS), or Dioxin.
   i. How to decide: Make this selection based on the type of laboratory method used for the analysis of the chemical.

iii. **Volatile Compound** – (APS Calculator Only) Choices: "Yes" (volatile) or "No" (Non-volatile)
   i. How to decide: This information is not based on the chemical analytical method. Use best professional judgment regarding the potential for a chemical to migrate from soil or water into the air. Note that EPA identifies chemicals that have a Henry's Law Constant greater than 10^{-5} atm-m^3/mol as potentially volatile.
      - OSWER Technical Guide For Assessing And Mitigating The Vapor Intrusion Pathway From Subsurface Vapor Sources To Indoor Air (EPA June 2015, Section 3.1)
      - Risk Assessment Guidance for Superfund Part B (EPA December 2022, Section 3.1.1)

iv. **Toxicity and Mutagenicity** – Consult the following sources to obtain toxicity values, information on mutagenicity, and supporting information.
   - EPA's Integrated Risk Information System (IRIS)
   - ATSDR Minimal Risk Levels (MRLs)

- EPA's Provisional Peer-Reviewed Toxicity Values (PPRTVs)
- California Environmental Protection Agency Chemical Database
- Other Sources: The CompTox Dashboard provides a summary of available toxicity values under the Hazard Section. This dashboard may be helpful in identifying if any additional sources of toxicity information are available. Consult with the original sources for the toxicity information to determine whether to use that information.

Toxicity values from each of these sources should be entered into the calculator and the selected toxicity value to be used in calculating the criteria indicated. The choice of which toxicity value to use and the determination of whether a chemical is potentially mutagenic should be made on the strength of information supporting the development of the values. Note, within the calculator the choices regarding mutagenicity are "Yes" or "No".

A Technical Support Memorandum should be provided with any criteria request to identify the toxicological information evaluated and the rationale for the selection of the toxicity value and mutagenicity status used to derive the criteria.

v. **Known Human Carcinogen** – Choices: "Yes" or "No" (Non-volatile) (APS Calculator Only)

This information is used in the calculation of Surface Water Protection Criteria. Answer "yes" for any chemical where the studies indicate strong evidence of carcinogenicity to humans (EPA 2005). This information should be available from the studies evaluated for determining appropriate toxicity information or the chemical may be referred to as a "Human Carcinogen" or a Class A or Class 1 carcinogen (IARC Classification). Additional details should be provided in the Technical Support Memo to support the selection for this parameter.

- EPA Guidelines for Carcinogen Risk Assessment March 2005
- International Agency for Research on Cancer Hazard Classifications 2023 Update

vi. **Laboratory Reporting Limits for Soil and Water**

Information on the analytical quantification levels (Reporting Limits) is used for all criteria calculations. This information can be gathered from the CTDEEP Reasonable Confidence Protocols or directly from the laboratory method documentation. Reporting levels for soil **must** be expressed as mg/kg and for water as µg/L. If this information is not provided, criteria will still be calculated but will not include consideration of analytical achievability.

vii. **Taste and Odor Thresholds** (APS Calculator Only)

Taste and Odor thresholds for water and air are used in deriving the Groundwater Protection Criteria and Volatilization Criteria. Values may be obtained from the CTDEEP Recommended Taste and Odor Thresholds for Criteria Development or from published literature. Additional details should be provided in the Technical Support Memo to support the selection for this parameter.

viii. **Indoor Air Reference Conditions** (APS Calculator Only)

Indoor Air Reference Condition values (µg/m^3) for Residential and Industrial-Commercial settings are used in deriving Volatilization Criteria. Values may be obtained from the CTDEEP Recommended Indoor Air Reference Conditions for Criteria Development or from published literature. Additional details should be provided in the Technical Support Memo to support the selection for this parameter.

ix. **Bioaccumulation Factors and High Potential to Bioaccumulate** (APS Calculator Only)

Bioaccumulation is the uptake of a substance into an organism from exposure to environmental media through all exposure pathways including food chain transfers. Bioaccumulation Factors are needed to calculate Surface Water Protection Criteria. Values can be presented either as a single value applicable across all fish trophic levels or can be provided as a series of Bioaccumulation Values for fish from Trophic Levels 2, 3, and 4. Values must be provided for all three trophic levels in order to correctly calculate the criteria if a single estimate is not used. Additional details should be provided in the Technical Support Memo to support the selection for this parameter.

The values can be obtained through published literature, EPA Human Health Water Quality Criteria Documents, or the EPA EcoTox Database. Measured or modeled Bioaccumulation Factors may also be available from the EPA CompTox Dashboard or may be modeled through the EPA EPI Suite model. Further guidance on selecting values is available through the EPA Guidance on Selecting Bioaccumulation Factors.

- EPA Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000)
- EPA Development of National Bioaccumulation Factors: Supplemental Information for EPA's 2015 Human Health Criteria Update

A designation of whether a chemical has a high potential to bioaccumulate can be based on several considerations including:

- Identification of a chemical by EPA as a Persistent, Bioaccumulative, and Toxic Chemical
- Chemical for which CT has established a Connecticut Fish Consumption Advisory
- Chemicals with Bioaccumulation Factors or Bioconcentration Factors greater than or equal to 1,000 or that have an Octanol-Water Partition Coefficient (K_{ow}) value that is $\geq$ 4.2 (EPA Exposure Assessment Tools by Media – Aquatic Biota). Octanol-Water Partition Coefficients are available in the EPA CompTox Dashboard (Physical-Chemical Properties) and through other sources that provide information on chemicals.

x. **Relative Source Contribution (RSC)** (APS Calculator Only)

Relative Source Contribution is used in the calculation of Surface Water Protection Criteria. It accounts for the amount of exposure to a particular chemical outside of the consumption of fish and water. The value may range from 0.2 to 0.8 (20% to 80%). A chemical-specific value may be calculated using EPA guidance. A value of 0.2 is the default value for the RSC which should be used in the calculator unless a chemical-specific value is developed. Values lower than 0.2 should not be used. Additional details should be provided in the Technical Support Memo to support the selection for this parameter.

- EPA Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000)

xi. **Water Quality Criteria, Benchmarks and Health Designations** (APS Calculator Only)

Established Water Quality Criteria and recommended Water Quality Benchmarks are considered during the calculation of Surface Water Protection Criteria.

- Connecticut Human Health and Aquatic Life Water Quality Criteria (µg/l) are available in the Connecticut Water Quality Standards.
- Connecticut Recommended Water Quality Benchmarks for both human health and aquatic life are available on the Connecticut Water Quality Standards web page.

Proposed Aquatic Life Chronic Water Quality Benchmarks are values to be proposed for use at a site. The following sources can be used to develop these benchmarks.

- Site-specific values may be calculated using information from the EPA EcoTox database or published literature and calculated using EPA Recommendations for deriving aquatic life criteria.
- EPA nationally recommended water quality criteria
- Water Quality Criteria available from other States

Health Designations provide information related to the development of Human Health Water Quality Criteria or Benchmarks. This information is available in the table of Water Quality Criteria within the Connecticut Water Quality Standards and the Connecticut Recommended Water Quality Benchmark documents. The APS calculator calculates the Health Designation for site-specific human health water quality benchmarks developed using the calculator. The following Health Designations are used:

- A: For chemicals that are known human carcinogens
- C: For all other carcinogens
- TT: Threshold toxicants. Chemicals that don't cause toxicity through a carcinogenic mode of action
- HB: Chemicals that have a high potential to bioaccumulate

xii. **Site Constituent of Concern** (Alternative Exposure Scenario Criteria Calculator only) – Choices: "Yes" or "No"

The selection for Site Constituent of Concern is used to indicate which chemicals should be included in criteria calculations in the Alternative Exposure Scenario Criteria Calculator.

xiii. **Site-Specific Exposure Variables** (Alternative Exposure Scenario Calculator only)

- Alternative Scenario: Provide a name that describes the proposed exposure scenario. Additional details should be provided in the documentation to support the site-specific criteria request.

- Averaging Time (days) for non-carcinogens:
    - Adult: This value is the number of days in a year (365) x the Exposure Duration for Adults
    - Child: This value is the number of days in a year (365) x (the Exposure Duration for Children aged 0 to <2 years and the Exposure Duration for Children aged 2 to <6 years)
- Exposure Duration (years): This is the amount of time that people in the following age groups may be present on site
    - Child aged 0 to <2 years
    - Child aged 2 to <6 years
    - Child aged 6 to <16 years
    - Person aged 16 to < 30 years
    - Adult
- Exposure Frequency (days/year): This is the number of days per year that people of any age may be exposed or present at the site
- Soil Ingestion Rate (mg/day): This is the amount of incidental soil ingestion that may occur as a result of the site-specific exposure scenario. Additional details should be provided in the documentation to support the site-specific request.

III. Getting Started: Data Entry

IMPORTANT:

- For both the APS Criteria and Alternative Exposure Scenario Criteria calculators, you **must** enter chemical information on the worksheet named **"ChemDataEntry"**. If this is NOT done, the calculator will NOT work.
- As information is entered into the calculators, pay attention to the units for each parameter so that data is entered correctly. Entering values using the wrong units will result in incorrect calculation of criteria.
- The cells that require data entry are colored **blue** and light blue. The rest of the spreadsheets are locked to prevent inadvertent changes to the calculators.

The **"ChemDataEntry"** worksheet is the primary worksheet where you will enter additional polluting substances (chemicals) and their various parameter values. This worksheet requires manual entries for the data on this worksheet (see Section II for details). Certain cells have drop-down lists (these cells are colored light blue). Make sure to use the drop-down arrow in the cell for data entry.

The substance information entered on the **"ChemDataEntry"** worksheet will automatically populate the other worksheets with the risk-based criteria calculations.

i. **Instructions (Calculator Specific)**
APS Calculator – Add new substance

1) Open the APS Calculator (Microsoft Excel workbook) and navigate to the "ChemDataEntry" worksheet (blue tab at bottom).

2) **To add a new substance** to the calculator, enter the information from the above Section III into the table on the "ChemDataEntry" worksheet.

3) There are four (4) toxicity columns ("G" through "J") on the "ChemDataEntry" worksheet. **DO NOT ENTER THE TOXICITY VALUES HERE**. Instead, navigate to the **"ToxValueEntry"** worksheet (next blue tab at bottom) to enter these values.

Please Note: When you navigate to the **"ToxValueEntry"** worksheet, you will see that the CASRN and Substance columns (in orange) have been automatically populated from the "ChemDataEntry" worksheet.

4) On the **"ToxValueEntry"** worksheet, use the **darker blue** cells to manually enter the below-listed sections. Then, use the drop-downs in the **lighter blue** cells to select the appropriate Toxicity Value and the Justification.

   a. Non-Cancer and Cancer Oral Toxicity Values

   b. Non-Cancer and Cancer Inhalation Toxicity Values

5) Return to the **"ChemDataEntry"** worksheet and you'll see that the selected Toxicity Values (in orange) have been filled in.

6) Columns "L" through "AG", enter the values from sources referenced in Section II.

ii. **Alternative Exposure Scenario Criteria Calculator - Add new scenario(s)**

1) Open the Alternative Exposure Scenario Criteria Calculator (Microsoft Excel workbook) and navigate to the "ChemDataEntry" worksheet (blue tab at bottom).
2) The Alternative Exposure Scenario Criteria Calculator comes preloaded with the RBCR substances and their values. For each preloaded substance in the table on the **"ChemDataEntry"** worksheet, you will see "RBCR" in the first column of the table. To identify that the RBCR substance is relevant to the remediation project, select "Yes" in the drop-down in the "Site Constituent of Concern" column (in light blue).
   IMPORTANT: The substances listed as "Yes" for column "Site Constituent of Concern" on the **"ChemDataEntry"** sheet, are the only chemicals that will be listed on the other worksheets and have criteria calculated (DEC_Summary, Soil_Adults&Children, and Soil_AdultsOnly).
3) If a substance is left blank for column "Site Constituent of Concern", these substances will not be on the other sheets.

4) **To add new substance(s)**, scroll down until you see the blue-colored cells (starting on row 91). Please use the first available row to add any additional substance(s).

   Figure 1 shows an example with cell C91 selected. This is the first column of the first available **blue** row. Use the drop-down to select "APS" for each new substance (chemical).

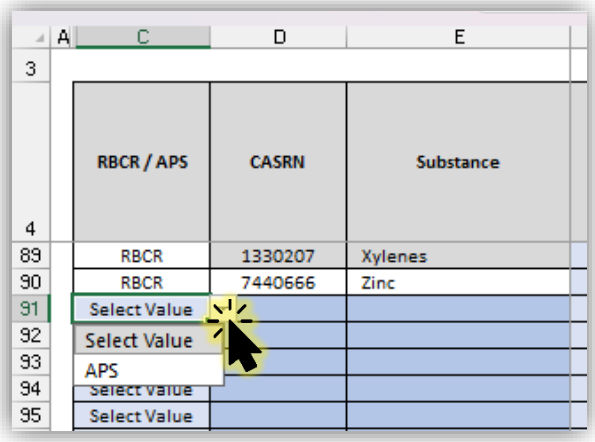


Figure1: (Step 4) Adding a new substance

5) For each chemical, enter the information from the above Section II.

6) There are two (2) toxicity columns (in orange, "J" and "K") on the "ChemDataEntry" worksheet. **DO NOT ENTER THE TOXICITY VALUES HERE.** Instead, navigate to the **"ToxValueEntry"** worksheet to calculate these values.

   Please Note: When you navigate to the **"ToxValueEntry"** worksheet (next blue tab at bottom), you will see that the CASRN and Substance columns (in orange) have been automatically populated from the "ChemDataEntry" worksheet.

7) On the **"ToxValueEntry"** worksheet, use the **darker blue** cells to manually enter the Non-Cancer and Cancer Oral Toxicity Values. Then, using the drop-downs in the lighter blue cells, select the appropriate "Reference Dose" and "Justification".

8) Return to the "ChemDataEntry" worksheet and you'll see that the Toxicity Values (in orange) have been filled in.

9) On the **"ChemDataEntry"** worksheet, the values for Res DEC and I/C DEC are provided for reference. For APS, the RBCR Criteria column indicates "NA" since values for these chemicals are not available within the RBCRs.

10) Navigate to the **"ExposureDataEntry"** worksheet (next blue tab at bottom). In the blue-colored cell in cell C2 add a description of the alternative exposure scenario for your site. Next, in the blue-colored cells in rows 5 through 18 under the "Value" column header, enter the scenario specific numerical values for the averaging time, exposure duration, exposure frequency, and soil ingestion rates. The "ExposureDataEntry" worksheet also includes default exposure values (in gray) that should not be changed and auto-calculated exposure values (in orange) for the alternative exposure scenario.

IV. Additional Worksheets (Calculator Specific)

After completing the steps from Section III the calculators will automatically populate the worksheets listed below.

IMPORTANT: It is your responsibility to check for any data entry errors throughout the calculator workbook. Errors will be highlighted in red and will include which worksheet to check.

iii. **APS Calculator – Additional Worksheets**

- **"APS_Summary" -** Table 1: APS Calculator: Criteria Values for Additional Polluting Substances
- **"DEC_Res" -** Table 2: Residential Direct Exposure Criteria Calculation Table
- **"DEC_IC" -** Table 3: Industrial/Commercial Direct Exposure Criteria Calculation Table
- **"DECMultiFam" -** Table 4: Managed Multifamily Residential Direct Exposure Criteria Calculation Table
- **"DECPassiveRec" -** Table 5: Passive Recreation Direct Exposure Criteria Calculation Table
- **"PMC_GA_GB" -** Table 6: Pollutant Mobility Criteria Calculation Table
- **"GWPC" -** Table 7: Groundwater Protection Criteria Calculation Table
- **"SWPC_HH" -** Table 8: Surface Water Protection Criteria - Human Health Calculation Table
- **"SWPC_AL" -** Table 9: Surface Water Protection Criteria - Aquatic Life Calculation Table
- **"TAC Res Calculations" -** Table 10: Residential Target Indoor Air Concentration (TAC) Calculation Table*
- **"TAC IC Calculations" -** Table 11: Industrial / Commercial Target Indoor Air Concentration (TAC) Calculation Table*
- **"Volatilization Criteria Calcs" -** Table 12: Volatilization Criteria Calculation Table*

  * These workbooks will ONLY list the volatile substances from the "ChemDataEntry" worksheet. If the substance is not marked as volatile on the "ChemDataEntry" worksheet, then the substance will not appear in these tables.

iv. **Alternative Exposure Scenario Criteria Calculator**

- **"DEC_Summary" -** Table 1: Alternative Exposure Scenario Calculator: Direct Exposure Criteria
- **"Alt-Exposure_Summary" -** Table 2: Site-Specific Alternative Exposure Values
- **"Soil_Adults&Children" -** Table 3: Alternative Exposure Scenario Direct Exposure Criteria (Adults and Children)
- **"Soil_AdultsOnly" -** Table 4: Alternative Exposure Scenario Direct Exposure Criteria (Adults only)

V. Requesting APS or Alternative Exposure Criteria

A copy of the calculator used to develop the requested criteria with the associated Technical Support Memo should be submitted through REACT and in accordance with the instructions on Requesting the Commissioner's Approval of Additional Polluting Substances (APS) and/or Alternative Criteria.

Appendix A: Equations Used in Calculators

Direct Exposure Criteria

Residential Risk-based Direct Exposure Criteria Formulas

For substances that are non-carcinogenic:

$$DEC_{res}\left(\frac{mg}{kg}\right) = \frac{RfD \times HI}{\left(\left(\frac{IR_c \times ED_c \times EF \times CF_{soil}}{BW_c \times AT_c}\right) + \left(\frac{IR_a \times ED_a \times EF \times CF_{soil}}{BW_a \times AT_a}\right)\right)}$$

For substances that are carcinogenic:

$$DEC_{res}\left(\frac{mg}{kg}\right) = \frac{RL/_{CSF}}{\left(\left(\frac{IR_c \times ED_c \times EF \times CF_{soil}}{BW_c \times AT}\right) + \left(\frac{IR_a \times ED_a \times EF \times CF_{soil}}{BW_a \times AT}\right)\right)}$$

Where:

Variable	Description	Value	Units
AT	Averaging Time – Carcinogen	25,550	days
AT_a	Averaging Time – Adult Non-carcinogen	8760	days
AT_c	Averaging Time – Child Non-carcinogen	2190	days
BW_a	Body Weight – Adult	70	kg
BW_c	Body Weight – Child	15	kg
CF_{soil}	Conversion Factor for soil	0.000001	kg/mg
CSF	Cancer Slope Factor	chemical specific	$(mg/kg/d)^{-1}$
DEC_{res}	Direct Exposure Criteria – Risk-based	chemical specific	mg/kg
ED_a	Exposure Duration – Adult Non-carcinogen	24	years
ED_c	Exposure Duration – Child Non-Carcinogen	6	years
EF	Exposure Frequency	365	days/year
HI	Hazard Index	1	unitless
IR_a	Ingestion Rate – Adult	100	mg/day
IR_c	Ingestion Rate – Child	200	mg/day
RfD	Reference Dose	chemical specific	mg/kg/d
RL	Risk Level	0.000001	unitless

Simplified Formulas:

Substance Type	Residential DEC
Non-carcinogen	67,741.935 x RfD
Carcinogen	0.6125 / CSF

Industrial/Commercial Risk-based Direct Exposure Criteria Formulas

For substances that are non-carcinogenic:

$$DEC_{I/C}\left(\frac{mg}{kg}\right) = \frac{RfD \times HI \times BW \times AT_{nc}}{IR \times ED \times EF \times CF_{soil}}$$

For substances that are carcinogenic:

$$DEC_{I/C}\left(\frac{mg}{kg}\right) = \frac{\left({}^{RL}/_{CSF}\right) \times BW \times AT}{IR \times ED \times EF \times CF_{soil}}$$

Where:

Variable	Description	Value	Units
AT	Averaging Time – Carcinogen	25550	days
ATnc	Averaging Time –Non-carcinogen	9125	days
BW	Body Weight – Adult	70	kg
CF_{soil}	Conversion Factor for soil	0.000001	kg/mg
CSF	Cancer Slope Factor	chemical specific	$(mg/kg/d)^{-1}$
$DEC_{I/C}$	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

Simplified Formulas:

Substance Type	Industrial/Commercial DEC
Non-carcinogen	2,044,000 x RfD
Carcinogen	5.7232 / CSF

Passive Recreation Risk-based Direct Exposure Criteria Formulas

For non-carcinogenic substances:

Child Passive Recreation Exposures

$$DEC_{PRec}\left(\frac{mg}{kg}\right) = \frac{RfD \times HI \times BW_{(0-6)} \times AT_{c_PRec}}{SIR_{(0-6)_PRec} \times EF_{PRec} \times ED_{(0-6)} \times CF_{soil}}$$

For carcinogenic substances:

Exposure to Child and Adult Passive Recreators:

$$DEC_{PRec}\left(\frac{mg}{kg}\right) = \frac{RL \times AT}{CSF \times CF_{soil} \times TSD_{PRec}}$$

Where:

TSD_{PRec} (mg/kg) = $SD_{0\text{-}6_PRec}$ + SD_{a_PRec}

$SD_{0\text{-}6_PRec}$ (mg/kg) = ($SIR_{(0\text{-}6)_PRec}$ x $ED_{(0\text{-}6)}$ x EF_{PRec}) / $BW_{(0\text{-}6)}$

SD_{a_PRec} (mg/kg) = (SIR_{a_PRec} x ED_{a} x EF_{PRec}) / BW_{a}

For Mutagenic substances:

Exposure to Child and Adult Passive Recreators:

$$DEC_{PRec}\left(\frac{mg}{kg}\right) = \frac{RL \times AT}{CSF \times CF_{soil} \times TSDM_{PRec}}$$

Where:

$TSDM_{PRec}$ (mg/kg) = $SD_{0\text{-}2PRec}$ + $SD_{2\text{-}6PRec}$ + $SD_{6\text{-}16PRec}$ + $SD_{16\text{-}30PRec}$

$SD_{0\text{-}2_PRec}$ (mg/kg) = ($SIR_{(0\text{-}2)_PRec}$ x $ADAF_{(0\text{-}2)}$ x $ED_{(0\text{-}2)}$ x EF_{PRec}) / $BW_{(0\text{-}2)}$

$SD_{2\text{-}6_PRec}$ (mg/kg) = ($SIR_{(2\text{-}6)_PRec}$ x $ADAF_{(2\text{-}6)}$ x $ED_{(2\text{-}6)}$ x EF_{PRec}) / $BW_{(2\text{-}6)}$

$SD_{6\text{-}16_PRec}$ (mg/kg) = ($SIR_{(6\text{-}16)_PRec}$ x $ADAF_{(6\text{-}16)}$ x $ED_{(6\text{-}16)}$ x EF_{PRec}) / $BW_{(6\text{-}16)}$

$SD_{16\text{-}30_PRec}$ (mg/kg) = ($SIR_{(16\text{-}30)_Prec}$ x $ADAF_{(16\text{-}30)}$ x $ED_{(16\text{-}30)}$ x EF_{PRec}) / $BW_{(16\text{-}30)}$

For Trichloroethylene – Carcinogenic and Mutagenic Risks

Exposure to Child and Adult Residents:

$$DEC_{PRec}\left(\frac{mg}{kg}\right) = \frac{RL \times AT}{\left((CSF_{TCE-M} \times CF_{soil} \times TSDM_{PRec}) + (CSF_{TCE-C} \times CF_{soil} \times TSD_{PRec})\right)}$$

Where:

Variable	Description	Value	Units
DEC_{PRec}	Direct Exposure Criteria for Soil Exposures	chemical specific	mg/kg
$ADAF_{(0-2)}$	Age Dependent Adjustment Factor for mutagenic cancer risk - 0–<2 years	10	unitless
$ADAF_{(16-30)}$	Age Dependent Adjustment Factor for mutagenic cancer risk - ages 16–<30 years	1	unitless
$ADAF_{(2-6)}$	Age Dependent Adjustment Factor for mutagenic cancer risk - ages 2–<6 years	3	unitless
$ADAF_{(6-16)}$	Age Dependent Adjustment Factor for mutagenic cancer risk - ages 6–<16 years	3	unitless
SD_{a_Prec}	Soil dose for adult residents	4,680	mg/kg
$SD_{(0-6)_PRec}$	Soil dose for ages 0–<6	7,213.87	mg/kg
$SD_{(0-2)_PRec}$	Soil dose for ages 0–<2	36,491.23	mg/kg
$SD_{(2-6)_PRec}$	Soil dose for ages 2–<6	14,427.75	mg/kg
$SD_{(6-16)_PRec}$	Soil dose for ages 6–<16	6,540.88	mg/kg
$SD_{(16-30)_PRec}$	Soil dose for ages 16–<30	2,730.00	mg/kg
AT	Averaging Time - Carcinogens	25,550	days
AT_{a_PRec}	Averaging Time - Adult Non-carcinogen	8,760	days
AT_{c_PRec}	Averaging Time - Child Non-carcinogen	2,190	days
$BW_{(0-2)}$	Body Weight - ages 0–2 years	11.4	kg
$BW_{(0-6)}$	Body Weight - ages 0–<6 years	17.3	kg
$BW_{(16-30)}$	Body Weight - ages 16–<30 years	80	kg
$BW_{(2-6)}$	Body Weight - ages 2–<6 years	17.3	kg
$BW_{(6-16)}$	Body Weight - ages 6–<16 years	47.7	kg
BW_a	Body Weight - Adult	80	kg
CF_{soil}	Conversion Factor (kg/mg) for soil	0.000001	kg/mg
CSF	Cancer Slope Factor	chem specific	$(mg/kg/d)^{-1}$
CSF_{TCE-C}	Cancer Slope Factor for Trichloroethylene for non- mutagenic risks	chem specific	$(mg/kg/d)^{-1}$
CSF_{TCE-M}	Cancer Slope Factor for Trichloroethylene for mutagenic risks	chem specific	$(mg/kg/d)^{-1}$
$ED_{(0-2)}$	Exposure Duration - ages 0–<2 years	2	years
$ED_{(0-6)}$	Exposure Duration - ages 0–<6 years	6	years
$ED_{(16-30)}$	Exposure Duration - ages 16–<30 years	14	years
$ED_{(2-6)}$	Exposure Duration - ages 2–<6 years	4	years
$ED_{(6-16)}$	Exposure Duration - ages 6–<16 years	10	years

ED_a	Exposure Duration - Adult	24	years
$EF_{_PRec}$	Exposure Frequency Passive Recreation	208	days/year
HI	Hazard Index	1	unitless
$TSDM_{PRec}$	Total Soil Dose for children and adults (mutagens)	60,189.9	mg/kg
TSD_{PRec}	Total Soil Dose for children and adults (carcinogens)	11,893.9	mg/kg
RfD	Reference Dose	chem specific	mg/kg/d
RL	Risk Level	0.000001	unitless
$SIR_{(0\text{-}2)_PRec}$	Soil Ingestion Rate - ages 0–<2 years	100	mg/day
$SIR_{(0\text{-}6)_PRec}$	Soil Ingestion Rate - ages 0–<6 years	100	mg/day
$SIR_{(16\text{-}30)_PRec}$	Soil Ingestion Rate - ages 16–<30 years	75	mg/day
$SIR_{(2\text{-}6)_PRec}$	Soil Ingestion Rate - ages 2–<6 years	100	mg/day
SIR_{a_PRec}	Soil Ingestion Rate - Adult	75	mg/day
$SIR_{(6\text{-}16)_PRec}$	Soil Ingestion Rate - Ages 6–<16 years	50	mg/day

Simplified Equations for Passive Recreation:

For substances that are non-carcinogenic:

Child Recreators: RfD x 303,581.73

For substances that are carcinogens (<u>not mutagenic):</u>

Child & Adult: 2.15 / CSF

For substances that are mutagens:

Child & Adult: 0.42 / CSF

Trichloroethylene:

Child & Adult: $0.02555 \Big/ \left((CSF_{TCE-M} \times 0.06019) + \left(CSF_{TCE_C} \times 0.011894 \right) \right)$

Managed Multifamily Risk-based Direct Exposure Criteria Formulas

For non-carcinogenic substances:

Child Resident Exposures

$$DEC_{MMF}\left(\frac{mg}{kg}\right) = \frac{RfD \times HI \times BW_{(0-6)} \times AT_{c_mmf}}{SIR_{(0-6)_mmf} \times EF_{mmf} \times ED_{(0-6)} \times CF_{soil}}$$

For carcinogenic substances:

Exposure to Child and Adult Residents:

$$DEC_{MMF}\left(\frac{mg}{kg}\right) = \frac{RL \times AT}{CSF \times CF_{soil} \times TSD_{mmf}}$$

Where:

TSD_{mmf} (mg/kg) = $SD_{0\text{-}6_mmf} + SD_{a_mmf}$

$SD_{0\text{-}6_mmf}$ (mg/kg) = ($SIR_{(0\text{-}6)_mmf}$ x $ED_{(0\text{-}6)}$ x EF_{mmf}) / $BW_{(0\text{-}6)}$

SD_{a_mmf} (mg/kg) = (SIR_{a_mmf} x ED_a x EF_{mmf}) / BW_a

For mutagenic substances:

Exposure to Child and Adult Residents:

$$DEC_{MMF}\left(\frac{mg}{kg}\right) = \frac{RL \times AT}{CSF \times CF_{soil} \times TSDM_{mmf}}$$

Where:

$TSDM_{mmf}$ (mg/kg) = $SD_{0\text{-}2_mmf} + SD_{2\text{-}6_mmf} + SD_{6\text{-}16_mmf} + SD_{16\text{-}30_mmf}$

$SD_{0\text{-}2_mmf}$ (mg/kg) = ($SIR_{(0\text{-}2)_mmf}$ x $ADAF_{(0\text{-}2)}$ x $ED_{(0\text{-}2)}$ x EF_{mmf}) / $BW_{(0\text{-}2)}$

$SD_{2\text{-}6_mmf}$ (mg/kg) = ($SIR_{(2\text{-}6)_mmf}$ x $ADAF_{(2\text{-}6)}$ x $ED_{(2\text{-}6)}$ x EF_{mmf}) / $BW_{(2\text{-}6)}$

$SD_{6\text{-}16_mmf}$ (mg/kg) = ($SIR_{(6\text{-}16)_mmf}$ x $ADAF_{(6\text{-}16)}$ x $ED_{(6\text{-}16)}$ x EF_{mmf}) / $BW_{(6\text{-}16)}$

$SD_{16\text{-}30_mmf}$ (mg/kg) = ($SIR_{(16\text{-}30)_mmf}$ x $ADAF_{(16\text{-}30)}$ x $ED_{(16\text{-}30)}$ x EF_{mmf}) / $BW_{(16\text{-}30)}$

For Trichloroethylene – Carcinogenic and Mutagenic Risks

Exposure to Child and Adult Residents:

$$DEC_{MMF}\left(\frac{mg}{kg}\right) = \frac{RL \times AT}{\left(\left(CSF_{TCE-M} \times CF_{soil} \times TSDM_{mmf}\right) + \left(CSF_{TCE-C} \times CF_{soil} \times TSD_{mmf}\right)\right)}$$

Where:

Variable	Description	Value	Units
DEC_{MMF}	Direct Exposure Criteria for Soil Exposures	chemical specific	mg/kg
$ADAF_{(0-2)}$	Age Dependent Adjustment Factor for mutagenic cancer risk - 0–<2 years	10	unitless
$ADAF_{(16-30)}$	Age Dependent Adjustment Factor for mutagenic cancer risk - ages 16–<30 years	1	unitless
$ADAF_{(2-6)}$	Age Dependent Adjustment Factor for mutagenic cancer risk - ages 2–<6 years	3	unitless
$ADAF_{(6-16)}$	Age Dependent Adjustment Factor for mutagenic cancer risk - ages 6–<16 years	3	unitless
SD_{a_mmf}	Soil dose for adult residents	5475	mg/kg
$SD_{(0-6)_mmf}$	Soil dose for ages 0–<6 years	12658.96	mg/kg
$SD_{(0-2)_mmf}$	Soil dose for ages 0–<2 years	64,035.09	mg/kg
$SD_{(2-6)_mmf}$	Soil dose for ages 2–<6 years	25,317.92	mg/kg
$SD_{(6-16)_mmf}$	Soil dose for ages 6–<16 years	11,477.99	mg/kg
$SD_{(16-30)_mmf}$	Soil dose for ages 16–<30 years	3,193.75	mg/kg
AT	Averaging Time - Carcinogens	25,550	days
AT_{a_mmf}	Averaging Time - Adult Non-carcinogen	8,760	days
AT_{c_mmf}	Averaging Time - Child Non-carcinogen	2,190	days
AT_{sw_mmf}	Averaging Time Adult site worker non-carcinogen	9,125	days
$BW_{(0-2)}$	Body Weight - ages 0–<2 years	11.4	kg
$BW_{(0-6)}$	Body Weight - ages 0–<6 years	17.3	kg
$BW_{(16-30)}$	Body Weight - ages 16–<30 years	80	kg
$BW_{(2-6)}$	Body Weight - ages 2–<6 years	17.3	kg
$BW_{(6-16)}$	Body Weight - ages 6–<16 years	47.7	kg
BW_a	Body Weight - Adult	80	kg
CF_{soil}	Conversion Factor (kg/mg) for soil	0.000001	kg/mg
CSF	Cancer Slope Factor	chem specific	$(mg/kg/d)^{-1}$
CSF_{TCE-C}	Cancer Slope Factor for Trichloroethylene carcinogenic risks	chem specific	$(mg/kg/d)^{-1}$
CSF_{TCE-M}	Cancer Slope Factor for Trichloroethylene for mutagenic risks	chem specific	$(mg/kg/d)^{-1}$
$ED_{(0-2)}$	Exposure Duration - ages 0–<2 years	2	years

$ED_{(0\text{-}6)}$	Exposure Duration - ages 0–<6 years	6	years
$ED_{(16\text{-}30)}$	Exposure Duration - ages 16–<30 years	14	years
$ED_{(2\text{-}6)}$	Exposure Duration - ages 2–<6 years	4	years
$ED_{(6\text{-}16)}$	Exposure Duration - ages 6–<16 years	10	years
ED_a	Exposure Duration - Adult	24	years
ED_{sw_mmf}	Exposure Duration site worker	25	years
EF_{mmf}	Exposure Frequency Multifamily Residential	365	days/year
EF_{sw_mmf}	Exposure Frequency site worker	250	days/year
HI	Hazard Index	1	unitless
TSD_{mmf}	Total Soil Dose for children and adults - carcinogens	18,134.0	mg/kg
$TSDM_{mmf}$	Total Soil Dose for children and adults - mutagens	104,024.7	mg/kg
RfD	Reference Dose	chem specific	mg/kg/d
RL	Risk Level	0.000001	unitless
$SIR_{(0\text{-}2)_mmf}$	Soil Ingestion Rate - ages 0–<2 years	100	mg/day
$SIR_{(0\text{-}6)_mmf}$	Soil Ingestion Rate - ages 0–<6 years	100	mg/day
$SIR_{(2\text{-}6)_mmf}$	Soil Ingestion Rate - ages 2–<6 years	100	mg/day
$SIR_{(6\text{-}16)_mmf}$	Soil Ingestion Rate - ages 6–<16 years	50	mg/day
$SIR_{(16\text{-}30)_mmf}$	Soil Ingestion Rate - age 16–<30 years	50	mg/day
SIR_{a_mmf}	Soil Ingestion Rate – Adult	50	mg/day
SIR_{sw_mmf}	Soil Ingestion Rate - Site Worker	100	mg/day

Simplified Equations for Managed Multifamily:

For substances that are non-carcinogenic:

Child Residents: RfD x 173,000

For substances that are carcinogens (<u>not mutagenic):</u>

Child & Adult: 1.41 / CSF

For substances that are mutagens:

Child & Adult: 0.25 / CSF

Trichloroethylene:

Child & Adult: $0.02555 \Big/ \left((CSF_{TCE-M} \times 0.104025) + (CSF_{TCE-C} \times 0.018134) \right)$

Pollutant Mobility Criteria

Pollutant Mobility Criteria Derivation:

Organic Substances:

PMC_{GA} (mg/kg) = GWPC (µg/L) x CF x AAF

PMC_{GB} (mg/kg) = GWPC (µg/L) x CF x AAF x DF

Inorganic Substances:

PMC_{GA} (mg/L) = GWPC (µg/L) x CF

PMC_{GB} (mg/L) = GWPC (µg/L) x CF x DF

Where:

Variable	Description	Value	Units
AAF	Analytical Adjustment Factors	20	unitless
CF	Conversion Factor	0.001	mg/µg
DF	Dilution Factor	10	unitless
GWPC	Groundwater Protection Criteria	chemical specific	µg/L
PMC	Pollutant Mobility Criteria	chemical specific	mg/kg or mg/L

Simplified Formulas

GA Areas:

Organic Chemicals: PMC (mg/kg) = GWPC x 0.02

Inorganic Chemicals: PMC (mg/L) = GWPC x 0.001 (based on results from a leaching test)

GB Areas:

Organic Chemicals: PMC (mg/kg) = GWPC x 0.2

Inorganic Chemicals: PMC (mg/L) = GWPC x 0.01 (based on the results from a leaching test)

Groundwater Protection Criteria

Equations used to calculate risk-based Groundwater Protection Criteria:

For substances that are non-carcinogenic:

$$GWPC\ \left(\frac{\mu g}{L}\right) = \frac{RfD \times HI \times BW \times AT \times SA}{IR \times EF \times ED \times CF}$$

For substances that are carcinogenic:

$$GWPC\ \left(\frac{\mu g}{L}\right) = \frac{RL \times BW \times AT}{CSF \times IR \times EF \times ED \times CF}$$

Where:

Variable	Description	Value	Units
AT	Averaging Time	25550	days
BW	Body Weight	70	kg
CSF	Cancer Slope Factor	chemical specific	$(mg/kg/d)^{-1}$
CF	Conversion Factor	0.001	mg/µg
ED	Exposure Duration	70	years
EF	Exposure Frequency	365	days/year
GWPC	Groundwater Protection Criteria	chemical specific	µg/L
HI	Hazard Index	1	unitless
IR	Ingestion Rate	2	L/day
RfD	Reference Dose	chemical specific	mg/kg/d
RL	Risk Level	1.00E-06	unitless
SA	Source Allocation	0.2	unitless

Simplified Formulas:

Substance Type	GWPC µg/L
Non-carcinogen	7000 x RfD
Carcinogen	0.035 / CSF

Surface Water Protection Criteria

Fish Consumption Only

$$\text{Non-carcinogenic: AWQC } \left(\frac{\mu g}{L}\right) = \frac{\text{RfD}\left(\frac{mg}{kg}\text{-d}\right) \times \text{RSC} \times \text{BW (kg)} \times \text{CF}\left(\frac{\mu g}{mg}\right)}{\sum_{i=2}^{4}\left(\text{FCR}_i\left(\frac{kg}{d}\right) \times \text{BAF}_i\left(\frac{L}{kg}\right)\right)}$$

$$\text{Carcinogenic: AWQC } \left(\frac{\mu g}{L}\right) = \frac{\frac{10^{-6}}{\text{CSF}\left(\frac{mg}{kg}\text{-d}\right)} \times \text{BW (kg)} \times \text{CF}\left(\frac{\mu g}{mg}\right)}{\sum_{i=2}^{4}\left(\text{FCR}_i\left(\frac{kg}{d}\right) \times \text{BAF}_i\left(\frac{L}{kg}\right)\right)}$$

Fish and Water Consumption

$$\text{Non-carcinogenic: AWQC } \left(\frac{\mu g}{L}\right) = \frac{\text{RfD}\left(\frac{mg}{kg}\text{-d}\right) \times \text{RSC} \times \text{BW (kg)} \times \text{CF}\left(\frac{\mu g}{mg}\right)}{\text{DI}\left(\frac{L}{d}\right) + \sum_{i=2}^{4}\left(\text{FCR}_i\left(\frac{kg}{d}\right) \times \text{BAF}_i\left(\frac{L}{kg}\right)\right)}$$

$$\text{Carcinogenic: AWQC } \left(\frac{\mu g}{L}\right) = \frac{\frac{10^{-6}}{\text{CSF}\left(\frac{mg}{kg}\text{-d}\right)} \times \text{BW (kg)} \times \text{CF}\left(\frac{\mu g}{mg}\right)}{\text{DI}\left(\frac{L}{d}\right) + \sum_{i=2}^{4}\left(\text{FCR}_i\left(\frac{kg}{d}\right) \times \text{BAF}_i\left(\frac{L}{kg}\right)\right)}$$

Where:

Variable	Description	Value	Units
AWQC	Ambient Water Quality Criteria	chemical specific	µg/L
BCF	Bioconcentration Factor	chemical specific	unitless
BW	Body Weight	80	kg
CF	Conversion Factor	1000	µg/mg
CSF	Cancer Slope Factor	chemical specific	$(mg/kg/d)^{-1}$
DI	Drinking Water Intake	2.4	L/d
FCR_i	Fish consumption rate	See note below	
BAF_i	Bioaccumulation factor	See note below	
RfD	Reference Dose	chemical specific	mg/kg/d
RSC	Relative Source Contribution	chemical specific	unitless
RL	Risk Level	1.00E-06	unitless
WQC	Water Quality Criteria	chemical specific	µg/L

Notes:

$\sum^{4}_{i=2}$ Summation of values for aquatic trophic levels (TLs), where the letter *i* stands for the TLs to be considered, starting with TL2 and proceeding to TL4

FCR – Fish Consumption Rates

- Total Consumption, if trophic level-specific BAF data is not available: 22 gm/d
- Trophic Level 2 Consumption Rate: 7.6 gm/d
- Trophic Level 3 Consumption Rate: 8.6 gm/d
- Trophic Level 4 Consumption Rate: 5.1 gm/d

BAF – Bioaccumulation Rate

- These values are chemical specific and may be expressed as a Total BAF or as BAF specific to each Trophic Level

Calculation of Surface Water Protection Criteria

Surface Water Protection Criteria (SWPC) are designed to be applied under low flow conditions, consistent with the requirements for ambient water quality criteria. The Water Quality Standards (CTDEEP 2013a) specify that Water Quality Criteria are to be applied under low flow conditions which are defined as 7Q10 flow conditions for non-tidal waters and low tide for tidal waters. These flows were selected for consistency with the short term exposure assumptions on which the aquatic life criteria are based. Human health based Water Quality Criteria have different exposure periods related to the mode of action of the chemical, either noncancer or cancer based endpoints. This would translate to application under differing flows within the surface water, flows which were greater than the 7Q10 flow. For noncarcinogens, EPA recommended applying the criteria under 30Q2 flows, which Connecticut determined to be approximately 2x the 7Q10 flow. For carcinogens, EPA recommended applying the criteria under Mean Harmonic Flows, which Connecticut determined to be approximately 3x the 7Q10 flows. CT DEEP used these "flow factors" to address this issue. To derive SWPC, the human health based Water Quality Criteria for noncarcinogens are multiplied by 2 and Water Quality Criteria for carcinogens were multiplied by 3 to allow for application under 7Q10 flows. Exceptions to this are made for chemicals that were designated by EPA as known human carcinogens or for chemicals with a higher potential to bioaccumulate. For these chemicals, a flow factor of 1 was used.

In addition to considering the river flows under which SWPC were to be applied, the default SWPC are based on an assumption of 10:1 dilution being available within the surface water body.

Based on these considerations, the risk-based SWPC are calculated as the lower of:

- Water Quality Criterion for Chronic Freshwater Aquatic Life Protection x 10; or
- Human Health based Water Quality Criterion for Fish Consumption x Flow Factor x 10

Where:

Flow Factor = 1 for known human carcinogens or substances which may bioaccumulate
Flow Factor = 2 for non-carcinogenic substances
Flow Factor = 3 for carcinogenic substances

Target Indoor Air Concentrations and Volatilization Criteria

Residential Target Indoor Air Concentrations

Residential Risk-based Target Indoor Air Concentration Formulas

For substances that are non-carcinogenic:

$$TAC\ \left(\frac{\mu g}{m^3}\right) = \frac{HQ \times RfDi \times AT \times CF}{CexpF \times EF \times ED \times ET_A}$$

For substances that are carcinogenic:

$$TAC\ \left(\frac{\mu g}{m^3}\right) = \frac{RL \times AT_c}{CSFi \times CexpF \times CsensF \times EF \times ED \times ET_A}$$

Where:

Variable	Description	Value	Units
AT	Averaging Time – Non-carcinogen	10950	days
ATc	Averaging Time – Carcinogen	25550	days
CexpF	Children's Exposure Factor	2	unitless
CF	Conversion Factor	1000	µg/mg
CsensF	Children's Sensitivity Factor	# see note below	unitless
CSFi	Cancer Slope Factor – Inhalation	chemical specific	$m^3/\mu g$
ED	Exposure Duration	30	years
EF	Exposure Frequency	365	days/year
ET_A	Exposure to Air	(24hr/d)/(24hr/d)	unitless
HQ	Hazard Quotient	1	unitless
RfDi	Reference Dose – Inhalation	chemical specific	mg/m^3
RL	Risk Level	1.00E-06	unitless
TAC	Target Indoor Air Concentration	chemical specific	$\mu g/m^3$

#: CsensF = 1 for noncarcinogens and nonmutagenic carcinogens
CsensF = 2 for mutagenic carcinogens

Simplified Formulas:

Substance Type	Residential Target Indoor Air Concentration
Non-carcinogen:	500 x RfDi
Carcinogen:	1.1667×10^{-6} / (CSFi x CsensF)

Industrial Commercial Target Indoor Air Concentrations

Industrial/Commercial Risk-based Target Indoor Air Concentration Formulas

For substances that are non-carcinogenic:

$$TAC\ \left(\frac{\mu g}{m^3}\right) = \frac{HQ \times RfDi \times AT \times CF}{EF \times ED \times ET_A}$$

For substances that are carcinogenic:

$$TAC\ \left(\frac{\mu g}{m^3}\right) = \frac{RL \times AT_c}{CSFi \times EF \times ED \times ET_A}$$

Where:

Variable	Description	Value	Units
AT	Averaging Time – Non-carcinogen	9125	days
ATc	Averaging Time – Carcinogen	25550	days
CF	Conversion Factor	1000	µg/mg
CSFi	Cancer Slope Factor – Inhalation	chemical specific	$m^3/\mu g$
ED	Exposure Duration	25	years
EF	Exposure Frequency	250	days/year
ET_A	Exposure to Air	(8hr/d)/(24hr/d)	unitless
HQ	Hazard Quotient	1	unitless
RfDi	Reference Dose – Inhalation	chemical specific	mg/m^3
RL	Risk Level	1.00E-06	unitless
TAC	Target Indoor Air Concentration	chemical specific	$\mu g/m^3$

Simplified Formulas:

Substance Type	Industrial/Commercial Target Indoor Air Concentration
Non-carcinogen:	4380 x RfDi
Carcinogen:	$1.2264x10^{-5}$/ CSFi

Volatilization Criteria

Volatilization Criteria are designed to model concentrations of volatile substances in ground water and soil vapor such that if these substances were to enter the indoor air within a building, the recommended TAC would be met. The recommended risk-based remediation volatilization criteria for groundwater and soil vapor were calculated using the equations and assumptions used to derive the Proposed Revisions: Connecticut's Remediation Standard Regulations Volatilization Criteria (CTDEEP 2003).

Risk-based Volatilization Criteria Formulas

For Ground Water Volatilization Criteria:

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

For Soil Vapor Volatilization Criteria:

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

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

Where:

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

Where:

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

$B = (Q_{soil} \times L_{crack}) / (D^{eff}_{crack} \times \eta \times A_B)$ ***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	µg/L
TAC	Target Indoor Air Concentration	chemical specific	$\mu g/m^3$
α	Attenuation Factor for Diffusion and Advection	calculated	unitless
SVVC	Soil Vapor Volatization 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

Definition of Variables

Variable	Definition	Units
H	Chemical Specific Henry's Law constant	µg/m^3-vapor / µg/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

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

Default Input Values

Variable	Units	Typical Value Range [1]	Notes	Res GWVC	I/C GWVC	Res SVVC	I/C SVVC
H	µg/m³-vapor / µg/m³-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 I/C scenario.	12	19.9	12	19.9

Default Input Values (continued)

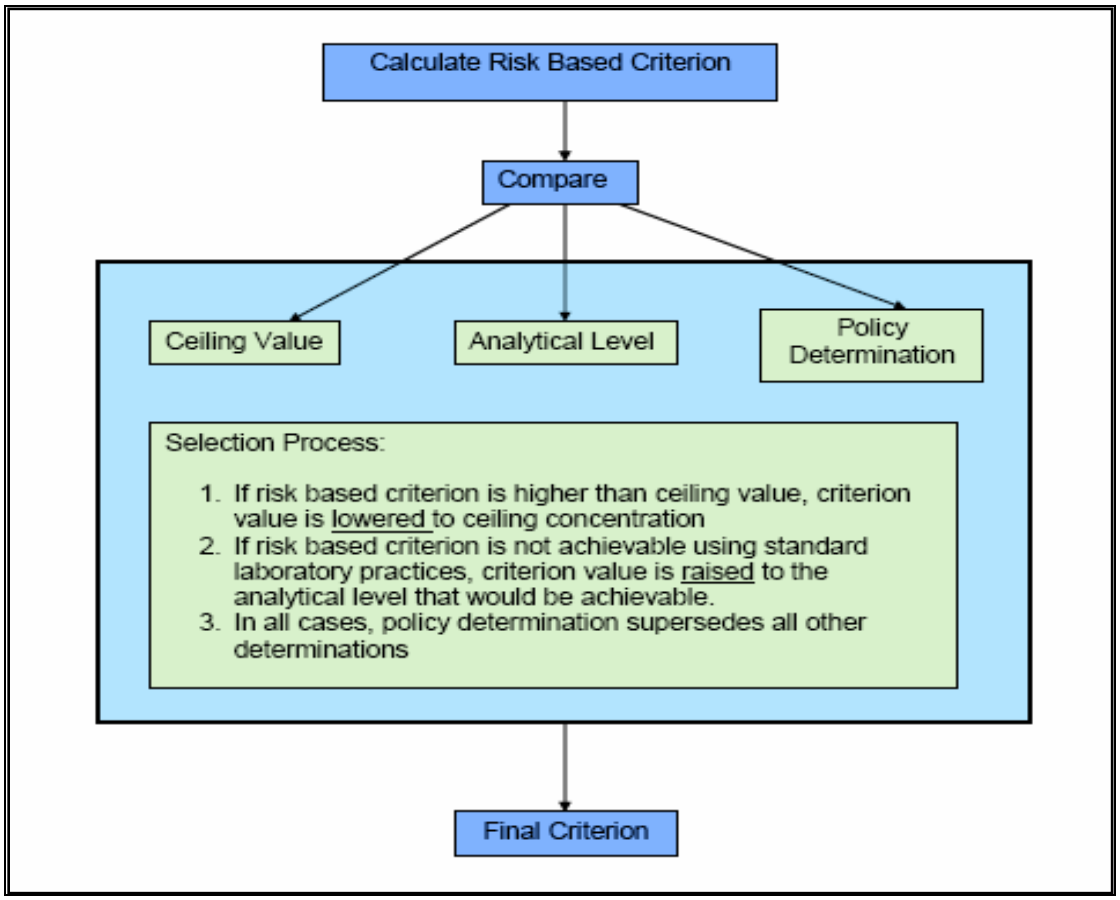
Variable	Units	Typical Value Range [1]	Notes	Res GWVC	I/C GWVC	Res SVVC	I/C SVVC
L_T	m	0.01 - 50	ASTM default values. 3 for Groundwater criteria and 1 for Soil Vapor criteria.	3	3	1	1
L_{cap}	m		ASTM default values. 0.05 for Groundwater criteria and 0 for Soil Vapor criteria.	0.05	0.05	0	0
L_{crack}	m	0.15 - 0.5	ASTM default value.	0.15	0.15	0.15	0.15
V_B/A_B	m	2 - 3	ASTM default values. 2 for Residential scenario and 3 for I/C 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.

Appendix B Risk Management: Adjustments to Risk-based Environmental Criteria

Once the risk-based values are calculated through the risk assessment process, using the toxicity values and formulas for each criteria type, the resulting risk-based criteria are adjusted, as necessary, to account for ceiling values, analytical levels or policy considerations.

Figure 1. Criteria Derivation Flow Chart



Ceiling Values

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, consideration of multiple pathways of exposure to the same or similar compounds or to complex mixtures.

Ceiling Values Used in Criteria Derivation

Criteria Type	Units	Volatile Substances	Semivolatile Substances	Pesticides	Inorganic
Direct Exposure Criteria: Residential	mg/kg	500	1,000	500	50,000
Direct Exposure Criteria: Industrial Commercial	mg/kg	1,000	2,500	1,000	50,000
Groundwater Protection Criteria	µg/L	1,000	1,000	1,000	1,000
Target Indoor Air Concentration	$\mu g/m^3$	500	NA	NA	NA
Groundwater Volatilization Criteria	µg/L	50,000	NA	NA	NA
Surface Water Protection Criteria	µg/L	10,000	10,000	10,000	10,000

Notes: NA - Not Applicable

Analytical Considerations

Adjustments to risk-based values were made if it was not possible to reliably quantify the amount of chemicals present using sensitive laboratory methods. In these cases, the criteria value was adjusted upwards to the analytical reporting associated with sensitive methods that were routinely used at remediation sites. The Quantification Limits identified for the Connecticut Reasonable Confidence Protocols were used for the analytical levels for soil and groundwater. Analytical levels are chemical-specific for soil and groundwater and are provided in the tables showing the derivation of the recommended criteria. For Volatilization Criteria, a value of 0.5 ppb was used as the analytical level to adjust Soil Vapor Volatilization Criteria, as recommended in the CTDEEP 2003 Volatilization Criteria document.

Policy Considerations

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

1. Consideration of General Ambient Concentrations

   For risk-based values that are below general background environmental concentrations, the criteria were adjusted up from the risk-based value to one consistent with estimated reference conditions. Within this document, this adjustment was applied to the Target Indoor Air Concentrations when published applicable data was available.

2. Significant Digits / Rounding

   The calculated criteria values adjusted to present values based on an appropriate number of significant digits. Standard rounding conventions were applied as necessary.

3. Consistency with Other Regulatory Programs

   EPA and CTDPH have recommended or promulgated Maximum Contaminant Levels (MCLs) and Action Levels for certain substances in drinking water supplies. Risk based GWPC criteria were compared to the established Maximum Contaminant Levels or Action Levels and adjusted, as needed, for consistency with these values.

4. Other Exposure Considerations

   In addition to direct impacts from ingesting or inhaling substances contained in groundwater or expect to be in indoor air, there is also a concern for odor from these substances to impact people, through bathing and showering exposures or generally through indoor air concentrations. Risk based values for Groundwater Protection Criteria and Target Indoor Air Concentrations were adjusted based on odor thresholds if the risk based criteria were above such thresholds.