Figure 1
Equation for Deriving Cleanup Target Levels
for Carcinogens in Groundwater

The formula for calculation is:

$$CTL(\mu g/L) = \frac{LRL \times BW \times CF}{[CSF_o] \times WI}$$

Parameter	Definition	Default Value
CTL	cleanup target level (µg/L)	-
LRL	lifetime risk level (unitless)	1×10^{-6}
BW	average body weight (kg)	70[a]
CF	conversion factor (µg/mg)	1000
CSF_o	oral cancer slope factor $(mg/kg/day)^{-1}$	Chemical-specific[b]
WI	water ingestion rate (L/day)	2

[a]Equations and default parameters from FDEP *Ground Water Guidance Concentration Manual,* Bureau of Drinking Water and Ground Water Resources, June 1994.
[b]Toxicity values from IRIS, HEAST or other sources as provided in Tables 5a and 5b of the DERM Technical Manual: Sources and Derivation of Toxicity Values Used in Calculations.

Example: hexachloro-1,3-butadiene, $CSF_o = 0.078\ (mg/kg/day)^{-1}$

$$CTL\ (\ \mu g/L) = \frac{1 \times 10^{-6} \times 70kg \times 1000\mu g/mg}{0.078(mg/kg/day)^{-1} \times 2L/day}$$

$$CTL = 0.5\ \mu g/L$$

Figure 2
Equation for Deriving Cleanup Target Levels
For Non-Carcinogens in Groundwater

The formula for calculation is:

$$\mathrm{CTL}\,(mg/\mathrm{L}) = \frac{\mathrm{RfD}_{oral} \times \mathrm{BW} \times \mathrm{RSC} \times \mathrm{CF}}{\mathrm{WI}}$$

Parameter	Definition (units)	Default Value
CTL	cleanup target level (µg/L)	-
RfD_{oral}	chronic oral reference dose (mg/kg/day)	Chemical-specific[b]
BW	average body weight (kg)	70[a]
RSC	relative source contribution (%)	20%
CF	conversion factor (µg/mg)	1000
WI	water ingestion rate (L/day)	2

Equations and default parameters from FDEP *Ground Water Guidance Concentration Manual,* Bureau of Drinking Water and Ground Water Resources, June 1994.
[b]Toxicity values from IRIS, HEAST, or other sources as provided in Tables 5a and 5b: Sources and Derivation of Toxicity Values Used in Calculations.

Example: 2-chlorophenol, RfD_{oral} = 0.005 mg/kg/day

$$\mathrm{CTL}\,(mg/\mathrm{L}) = \frac{0.005\ \mathrm{mg/kg/day} \times 70\ \mathrm{kg} \times 0.20 \times 1000\ mg/\mathrm{mg}}{2\ \mathrm{L/day}}$$

CTL = 35 µg/L

Figure 3A

Methodology Used to Calculate Freshwater and Marine Surface Water Cleanup Target Levels Based on Chronic Aquatic Toxicity

Steps:

1. Select data with document codes of "C" or "M" from EPA Aquatic Toxicity Information Retrieval (AQUIRE) Database.

2. Take no action for substances for which insufficient data are retrieved to allow a reasonable choice of sensitive organisms.

3. Select only animal LC_{50} data, except that plant data should be selected in the case of substances in which plant EC_{50} values for growth or photosynthesis, or LC_{50} values for biomass, are several orders of magnitude lower than animal LC_{50} values.

4. Ignore data from salmonid fishes (salmon and freshwater trout).

5. Select the test and organism showing the greatest sensitivity to the toxicant. Extreme outliers should be ignored during this procedure, and several other types of data (such as data in which the endpoint or concentration had to be recalculated by EPA for entry into the database, and data based only on active ingredients) should also be removed from consideration if more clearly applicable data are available for sensitive organisms.

6. A factor of 5% (1/20) should be applied to the animal LC_{50} data to generate a surface water CTL. If a plant LC_{50} or EC_{50} value was chosen, then that value becomes the guideline, without the use of a factor.

Figure 3B
Equations[a] Used to Calculate Freshwater or Marine Surface Cleanup Target Levels
Based on Human Health Endpoints

For Non-Carcinogens:

$$\text{CTL } (mg/L) = \frac{(\text{RfD}_{oral} \times \text{BW})}{(\text{FI} \times \text{BCF})} \times \text{CF}$$

For Carcinogens:

$$\text{CTL } (mg/L) = \frac{(\text{TR} \times \text{BW})}{(\text{CSF}_{oral} \times [FI \times BCF])} \times \text{CF}$$

Parameter	Definition	Default Value
CTL	Cleanup target level (µg/L)	n/a
CF	conversion factor (µg/mg)	1000
BW	body weight (kg)	70[a]
FI	fish ingestion rate (kg/day)	0.0065[a]
BCF	bioconcentration factor (mg toxicant/kg fish per mg toxicant/L water)	chemical-specific[a]
RfD_{oral}	oral reference dose (mg/kg/day)	chemical-specific[b]
CSF_{oral}	oral cancer slope factor $(mg/kg/day)^{-1}$	chemical-specific[b]
TR	target risk (unitless)	1×10^{-6}

[a]Equations, default parameters, and BCFs from USEPA *Technical Support Document for Water Quality-Based Toxics Control*, EPA/505/2-90-001, 1991.
[b]Toxicity values from IRIS, HEAST, or other sources as provided in Tables 5a and 5b: Sources and Derivation of Toxicity Values Used in Calculations.

Example: Cyhalothrin (karate), RfD_{oral} = 0.005 mg/kg/day and BCF = 10700 L/kg

$$\text{CTL } (mg/L) = \frac{0.005 \text{ mg/kg/day} \times 70 \text{ kg}}{0.0065 \text{kg/day} \times 10700 \text{L/kg}} \times 1000 \text{ mg/mg}$$

$$\text{CTL } = 5 \text{ mg/L}$$

Example: Acrylonitrile, CSF_{oral} = 0.54 $(mg/kg/day)^{-1}$ and BCF 0.4 L/kg

$$\text{CTL } (mg/L) = \frac{1x10^{-6} \times 70 \text{ kg}}{0.54(\text{mg/kg/day})^{-1} \times (0.0065 \text{kg/day} \times 0.4 \text{L/kg})} \times 1000 \text{ mg/mg}$$

$$\text{CTL } = 49.9 \text{ mg/L}$$

Figure 4
Model Equation for Developing Direct Exposure Soil Cleanup Target Levels

(Carcinogens)

$$CTL = \frac{TR \times BW \times AT}{EF \times ED \times FC \times \left[\left(CSF_o \times IR_o \times 10^{-6}\,kg/mg\right) + \left(CSF_d \times SA \times AF \times DA \times 10^{-6}\,kg/mg\right) + \left(CSF_i \times IR_i \times \left(\frac{1}{VF} + \frac{1}{PEF}\right)\right)\right]}$$

CTL = cleanup target level (mg/kg)
TR = target cancer risk (unitless)
BW = body weight (kg)
AT = averaging time (days)
EF = exposure frequency (days/yr)
ED = exposure duration (years)
FC = fraction from contaminated source (unitless)

IR_o = ingestion rate, oral (mg/day)
SA = surface area of skin exposed (cm^2/day)
AF = adherence factor (mg/cm^2)
DA = dermal absorption (unitless)
IR_i = inhalation rate (m^3/day)
VF = volatilization factor (m^3/kg)
PEF = particulate emission factor (m^3/kg)

CSF = cancer slope factor $(mg/kg/day)^{-1}$
CSF_o = oral
CSF_d = dermal
CSF_i = inhalation

Sample CTL Calculation for Direct Exposure (Aggregate Resident): BENZENE

$$CTL = \frac{0.000001 \times 59kg \times 25550days}{350d/yr \times 30yr \times 1 \times \left[\left(0.029(mg/kg/d)^{-1} \times 120mg/d \times 1x10^{-6}\,kg/mg\right) + \left(0.032(mg/kg/d)^{-1} \times 3674cm^2/d \times 0.2mg/cm^2 \times 0.01 \times 1x10^{-6}\,kg/mg\right) + \left(0.0273(mg/kg/d)^{-1} \times 15m^3/d \times \left(\frac{1}{3.3572x10^3} + \frac{1}{1.24x10^9}\right)\right)\right]}$$

$$CTL = \frac{1.5075}{10500 \times \left[\left(3.48 \times 10^{-6}\right) + \left(2.3514 \times 10^{-7}\right) + \left(1.2198 \times 10^{-4}\right)\right]} = \frac{1.5075}{10500 \times 1.2561x10^{-4}} = \frac{1.5075}{1.3198} = 1.1mg/kg \ddagger$$

Given: CSF_o = 0.029 $(mg/kg/day)^{-1}$
CSF_d = 0.032 $(mg/kg/day)^{-1}$
$_CSF_i$ = 0.0273 $(mg/kg/day)^{-1}$
VF = 3.3572 x 10^3 m^3/kg
PEF = 1.24 x 10^9 m^3/kg

‡All calculations carried out to 18 decimal places. For simplicity of demonstration, the calculated values above are not shown to the same precision.
Final CTL is rounded to two significant figures if >1 and to one significant figure if <1.

Figure 5
Model Equation for Developing Direct Exposure Soil Cleanup Target Levels

(Non-Carcinogens)

$$CTL = \frac{THI \times BW \times AT}{EF \times ED \times FC \times \left[\left(\frac{1}{RfD_o} \times IR_o \times 10^{-6}\ kg/mg\right) + \left(\frac{1}{RfD_d} \times SA \times AF \times DA \times 10^{-6}\ kg/mg\right) + \left(\frac{1}{RfD_i} \times IR_i \times \left(\frac{1}{VF} + \frac{1}{PEF}\right)\right)\right]}$$

CTL = cleanup target level (mg/kg)
THI = target hazard index (unitless)
BW = body weight (kg)
AT = averaging time (days)
EF = exposure frequency (days/yr)
ED = exposure duration (years)
FC = fraction from contaminated source (unitless)

IR_o = ingestion rate, oral (mg/day)
SA = surface area of skin exposed (cm^2/day)
AF = adherence factor (mg/cm^2)
DA = dermal absorption (unitless)
IR_i = inhalation rate (m^3/day)
VF = volatilization factor (m^3/kg)
PEF = particulate emission factor (m^3/kg)

RfD = reference dose (mg/kg/day)
RfD_o = oral
RfD_d = dermal
RfD_i = inhalation

Sample CTL Calculation for Direct Exposure (Child Resident): FLUORENE

$$CTL = \frac{1.00 \times 15kg \times 2190days}{350d/yr \times 6yr \times 1 \times \left[\left(\frac{1}{0.04mg/kg/d} \times 200mg/d \times 1x10^{-6}\ kg/mg\right) + \left(\frac{1}{0.02mg/kg/d} \times 1800cm^2/d \times 0.2mg/cm^2 \times 0.01 \times 1x10^{-6}\ kg/mg\right) + \left(\frac{1}{0.02mg/kg/d} \times 10m^3/d \times \left(\frac{1}{2.80802\ x\ 10^5} + \frac{1}{1.24\ x\ 10^9}\right)\right)\right]}$$

$$CTL = \frac{3.2850 \times 10^4}{2100 \times [(5.00 \times 10^{-3}) + (1.80 \times 10^{-4}) + (1.7810 \times 10^{-3})]} = \frac{3.2850 \times 10^4}{14.6181} = 2200\ mg/kg\ \ddagger$$

Given: RfD_o = 0.04 mg/kg/day
RfD_d = 0.02 mg/kg/day
RfD_i = 0.02 mg/kg/day
VF = 2.80802 x 10^5 m^3/kg
PEF = 1.24 x 10^9 m^3/kg

‡All calculations carried out to 18 decimal places. For simplicity of demonstration, the calculated values above are not shown to the same precision.
Final CTLs are rounded to two significant figures if >1 and to one significant figure if <1.

Figure 6
Derivation of the Particulate Emission Factor[a]

$$PEF\ (m^3/kg) = Q/C \times \frac{3600\ sec/hr}{0.036 \times (1 - V) \times (U_m/U_t)^3 \times F(x)}$$

Parameter	Definition (units)	Default
PEF	particulate emission factor (m^3/kg)	1.241005 x 10^9
Q/C	inverse of mean conc. at center of a 0.5-acre-square source (g/m^2-s per kg/m^3)	85.61[b]
V	fraction of vegetative cover (unitless)	0.5 (50%)
U_m	mean annual windspeed (m/s)	4.69
U_t	equivalent threshold value of windspeed at 7m (m/s)	11.32
F(x)	function dependent on U_m/U_t, derived using Cowherd et al. (1985)[c] (unitless)	0.194

[a]Equation taken from USEPA (1996b) *Soil Screening Guidance: Technical Background Document* EPA/540/R-95/128.

[b]Based on Q/C Value for Zone IX (Miami, FL) as listed in USEPA *Soil Screening Guidance*. The default is for 0.5 acre sites with undisturbed soil. Site-specific PEFs must be calculated for sites with contaminated areas which are significantly larger in size or if warranted based on site-specific conditions.

[c]Cowherd, C., Muleski, G., Engelhardt, P., and Gillette, D. (1985). *Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination*. EPA/600/8-85/002.

**All calculations carried out to 18 decimal places. For simplicity of demonstration, the calculated values below are not shown to the same precision.

Calculation of PEF based on Zone IX (Miami, FL) Q/C Value**:

$$PEF\ (m^3/kg) = 85.61 \left(\frac{g \cdot m^3}{kg \cdot m^2 \cdot s} \right) \times \frac{3600\ sec/hr}{0.036 \times (1 - 0.5) \times (4.69\ (m/s)/11.32\ (m/s))^3 \times 0.194} = 1.241005 \times 10^9\ (m^3/kg)$$

Figure 7
Equation Used for the Determination of the Volatilization Factor[a]

$$VF = Q/C \times CF \times \frac{(3.14 \times D_A \times T)^{1/2}}{2 \times \rho_b \times D_A}$$

$$D_A = \frac{\left[\left(q_a^{10/3} D_i H' + q_w^{10/3} D_w\right) / n^2\right]}{r_b K_d + q_w + q_a H'}$$

WHERE:

Model Parameters (Units)		Default Value
VF	Volatilization factor (m^3/kg)	-
D_A	Apparent diffusivity (cm^2/s)	-
CF	Conversion factor (m^2/cm^2)	10^{-4}
Q/C	Inverse of the mean concentration[b] (g/m^2-s per kg/m^3)	85.61[c]
T	Exposure interval (s)	ED × 3.1536x10^7 s/yr
ED	Exposure duration (years)	Exposure-specific[e]
N	Total soil porosity (L_{pore}/L_{soil})	1- (ρ_b/ρ_s)‡
W	Average soil moisture content (g_{water}/g_{soil})	0.1 (10%)‡
ρ_b	Dry soil bulk density (g/cm^3)	1.5‡
ρ_s	Soil particle density (g/cm^3)	2.65
θ_a	Air-filled soil porosity (L_{air}/L_{soil})	n - θ_w
θ_w	Water-filled soil porosity (L_{water}/L_{soil})	wρ_b
K_d	Soil-water partition coefficient L/kg)	$K_{oc} \times f_{oc}$
D_I	Diffusivity in air (cm^2/s)	Chemical-specific[d]
D_w	Diffusivity in water (cm^2/s)	Chemical-specific[d]
H	Henry's Law constant (atm-m^3/mol)	Chemical-specific[d]
H'	Dimensionless Henry's Law constant	H × 41
K_{oc}	Soil-organic carbon partition coefficient (L/kg)	Chemical-specific[d]
f_{oc}	Organic carbon content of soil (g/g)	0.006 (0.6%)‡

[a] Model equation taken from USEPA 1996 'Soil Screening Guidance: Technical Background Document.' EPA/540/R-95/128.

[b] Assumes the center of a 0.5 acre plot.

[c] Based on Q/C Value for Zone IX (Miami, FL) as listed in USEPA 'Soil Screening Guidance.' Based on a 0.5 acre site; site-specific PEFs must be calculated for sites which are significantly larger in size.

[d] Listed in Table 3.

[e] Based on Aggregate Resident exposure for a duration of 30 years (ED).

‡Value may be substituted with documented DERM accepted site-specific information.

Sample VF Calculation for Benzene Exposure**

**All calculations carried out to 18 decimal places. For simplicity of demonstration, the calculated values below are not shown to the same precision.

Given: $D_i = 0.088\ cm^2/s$
$D_w = 9.80 \times 10^{-6}\ cm^2/s$
H' = 0.22755000
T = 9.460800x10^8 s[e]
$K_{oc} = 59$ L/kg
$K_d = 0.35400$ L/kg

Then:

$$D_A = \frac{\left[\left(1.504996x10^{-2} \times 0.088 \times 2.27550x10^{-1}\right) + \left(1.793236x10^{-3} \times 9.80x10^{-6}\right) / 1.883232x10^{-1}\right]}{\left(1.5 \times 3.3540x10^{-1}\right) + (0.15) + (0.2839362 \times 0.2755)}$$

$$= \frac{1.600262x10^{-3}}{7.456097x10^{-1}}\ cm^2/s = 2.146x10^{-3}\ cm^2/s$$

And: $$VF = 85.61\left(\frac{g \cdot m^3}{kg \cdot m^2 \cdot s}\right) \times 1x10^{-4}\left(\frac{m^2}{cm^2}\right) \times \frac{\left(3.14 \times 2.1462x10^{-3}\left(\frac{cm^2}{s}\right) \times 9.46080x10^{8}(s)\right)^{\frac{1}{2}}}{2 \times 1.5 \times 2.1462x10^{-3}\left(\frac{cm^2}{s}\right)}$$

$$= \frac{2.1617x10^{1}}{6.4390x10^{-3}} = 3.3572x10^{3}\left(\frac{m^3}{kg}\right)$$

Figure 8
Equation for the Determination of Leachability-Based Cleanup Target Levels

$$\text{CTL (mg/kg)} = \text{GWCTL(} \mu\text{g/L)} \times \text{CF(mg/}\mu\text{g)} \times \text{DF} \times \left[K_{oc}\,(\text{L/kg}) \times f_{oc}\,(\text{g/g}) + \frac{q_w\,(L_{water}/L_{soil}) + q_a\,(L_{air}/L_{soil}) \times H'}{r_b\,(\text{g/cm}^3)} \right]$$

Parameter	Definition (units)	**Variables and Default**
GWCTL	Groundwater cleanup target level (µg/L)	Chemical-specific value[1]
CF	Conversion factor (mg/µg)	0.001
DF	Dilution factor (unitless)	20[2]
K_{oc}	Soil-organic carbon partition coefficient (L/kg)	Chemical-specific value
f_{oc}	Fraction organic carbon in soil (g/g)	0.002
Θ_w	Water-filled soil porosity (L_{water}/L_{soil})	$w\rho_b$
Θ_a	Air-filled soil porosity (L_{air}/L_{soil})	n - Θ_w
H	Henry's Law constant (atm-m^3/mol)	Chemical-specific value[2]
H'	Henry's Law constant (unitless)	$H \times 41$
ρ_b	Dry soil bulk density (g/cm^3)	1.5
w	Average soil moisture content (g_{water}/g_{soil})	0.2 (20%)
n	Total soil porosity (L_{pore}/L_{soil})	1-(ρ_b/ρ_s)
ρ_s	Soil particle density (g/cm^3)	2.65

[1]Groundwater cleanup target level (see Table 1).

[2]If the site is significantly larger than 0.5 acres or if warranted by site-specific conditions (such as a shallow water table), a lower DF may be required.

**All calculations carried out to 18 decimal places. For simplicity of demonstration, the calculated values below are not shown to the same precision. Final CTL is rounded to two significant figures if >1 and to one significant figure if <1.

Sample CTL Calculation for Benzene Migration into Groundwater:

Given: GWCTL = 1 µg/L
K_{oc} = 59 L/kg
H' = 0.227550

Then:

$$\text{CTL(mg/kg)} = 1.0\ \mu\text{g/L} \times 0.001\ \text{mg/}\mu\text{g} \times 20 \times \left[59\ \text{L/kg} \times 0.002\ \text{g/g} + \frac{0.3\ L_{water}/L_{soil} + \left(0.13396\ L_{air}/L_{soil} \times 0.205\right)}{1.5\ \text{g/cm}^3} \right] =$$

$$\text{CTL} = 0.007\ \text{mg/kg}\ **$$

Figure 9
Equation[a] Used for the Determination of C_{sat}

$$C_{sat} = \frac{S}{r_b}\left(K_d r_b + q_w + H' q_a\right)$$

Parameter	Definition (Units)	Default Value
C_{sat}	Soil saturation concentration (mg/kg)	-
S	Solubility in water (mg/L)	Chemical-specific[b]
ρ_s	Soil particle density (g/cm^3)	2.65
ρ_b	Dry soil bulk density(g/cm^3)	1.5
η	Total soil porosity (L_{pore}/L_{soil})	$1 - (\rho_b/\rho_s)$
θ_a	Air-filled soil porosity (L_{air}/L_{soil})	$\eta - \theta_w$
θ_w	Water-filled soil porosity (L_{water}/L_{soil})	$\omega\rho_b$
K_d	Soil-water partition coefficient (cm^3/g)	$K_{oc} \times f_{oc}$
ω	Average soil moisture content (kg_{water}/kg_{soil})	0.1 (10%)
H	Henry's Law constant ($atm\text{-}m^3/mol$)	Chemical-specific[b]
H'	Dimensionless Henry's Law constant	$H \times 41$
K_{oc}	Soil-organic carbon partition coefficient (L/kg)	Chemical-specific[b]
f_{oc}	Fraction organic carbon in soil (g/g)	0.006 (0.6%)

[a] Model equation taken from USEPA 1996b *Soil Screening Guidance: Technical Background Document*. EPA/540/R-95/128.

[b] Listed in Table 4.

**All calculations carried out to 18 decimal places. For simplicity of demonstration, the calculated values below are not shown to the same precision. C_{sat} values used as SRA standards are rounded to two significant figures if > 1 and to one significant figure if < 1.

Sample C_{sat} Calculation for Ethylbenzene**

Given:

$S = 169$ mg/L
$K_d = 2.178$ L/kg
$K_{oc} = 363$ L/kg
$H' = 0.32308$

Then:

$$C_{sat} = \frac{169\ mg/L}{1.5\ g/cm^3}\left(\left(2.178\ L/kg \times 1.5 g/cm^3\right) + \left(0.15\right) + \left(0.32308 \times 0.2839362\right)\right)$$

$$C_{sat} = 112.6667\ mg/L \times 3.5087\ L/kg$$

$$C_{sat} = 400\ mg/kg$$