CSSAB PFAS Workgroup Update

Presented at the July 15, 2026 CSSAB Meeting

Presented by CSSAB PFAS Workgroup Members
Colleen Costello, PG – CCC, LLC
Sean Fullmer, PG- Sanborn Head

Outline

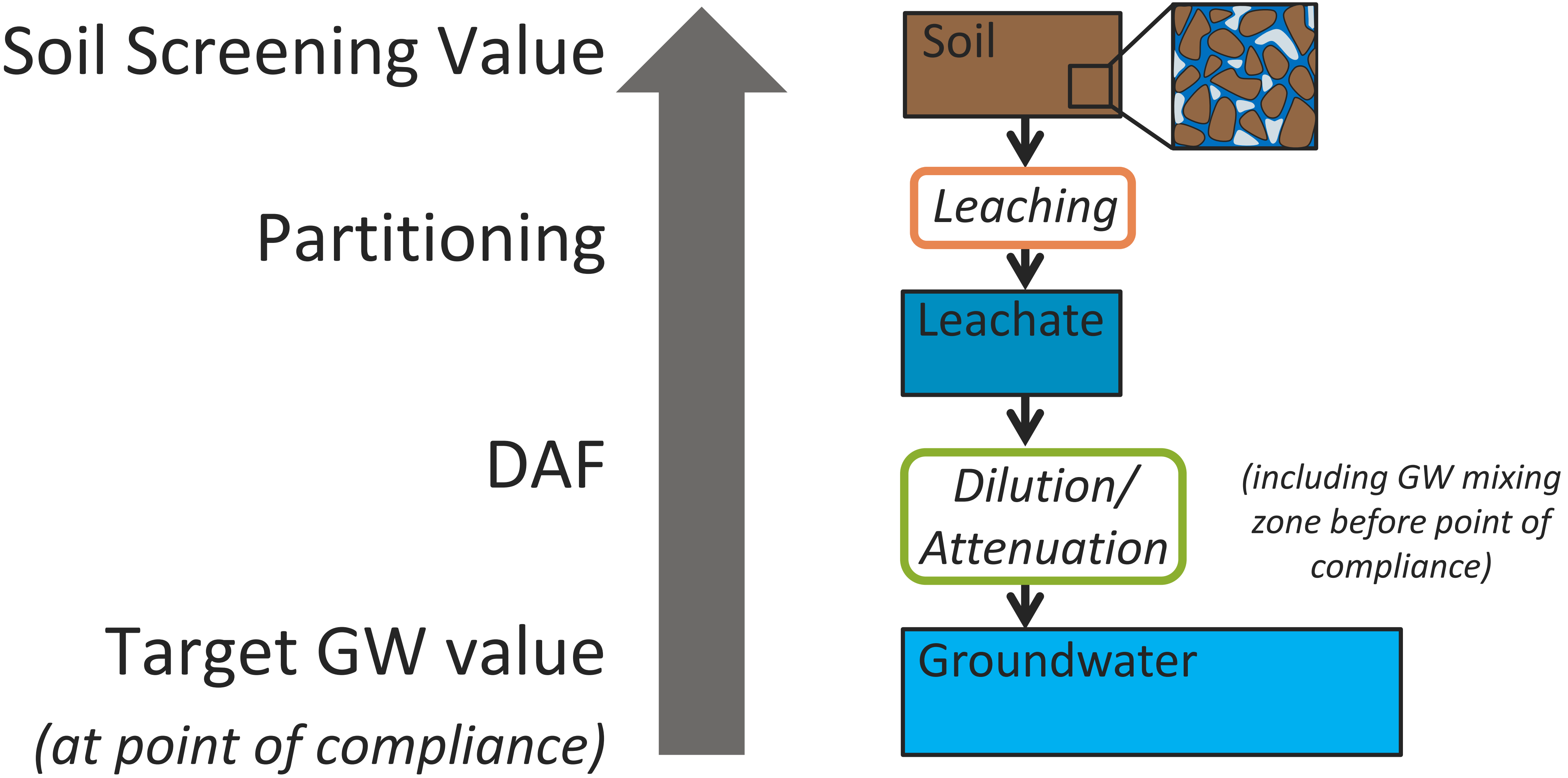
- Overview of Completed Activities – Colleen Costello
- Update from Modeling Subgroup- Sean Fullmer
  - Review of key fate and transport processes
  - Incorporating air-water interface into vadose zone
  - Sensitivity Analysis for air-water interface terms
  - Demonstration - PFAS-LEACH excel tool, highlight parameter selection (K_{oc}, K_{aw}, A_{aw})
  - Groundwater/Surface Water Act 2 F&T Tools
    - Quick Domenico (QD)
    - SWLOAD
    - Toxics Management Spreadsheet (TMS)
- Next Steps for generic soil to groundwater equation – Colleen Costello
- Overview of soil to groundwater equations in other states/federally – Colleen Costello
- Updated schedule for CSSAB PFAS Workgroup – Colleen Costello

DISCLAIMER: The information in this presentation is for discussion purposes only. Calculations, formulas, and numeric values are illustrative only; they currently are being reviewed and discussed within the CSSAB PFAS Workgroup, and presentation of such information at this time is not an endorsement of its use.

Overview of Completed Activities

- **CSSAB PFAS Workgroup - C**ontinues to meet monthly to review and discuss progress of subgroups
- **Subgroup 1** – Draft of text defining the challenge of fate and transport in Act 2 process, Core group of text reviewers for other sections of White Paper
- **Subgroup 2 & 3-** Completed summary of what other states/EPA/DOD doing, current Guidance and Current Research. Summary tables to be included as attachments to White Paper.
- **Subgroup 4** - Continues to act as resource for other subgroups on PFAS fate and transport technical topics.
- **Subgroup 5** – Identified potential generic soil to groundwater equation modifications for PFAS and other Act 2 F&T models (main focus of today's presentation)
- **Subgroup 6** – Continuing work on supporting information relating for PFAS fate and transport (PFAS sources, background and Site Conceptual Model) to be included in White Paper as reference.

Soil Screening Value Calculation



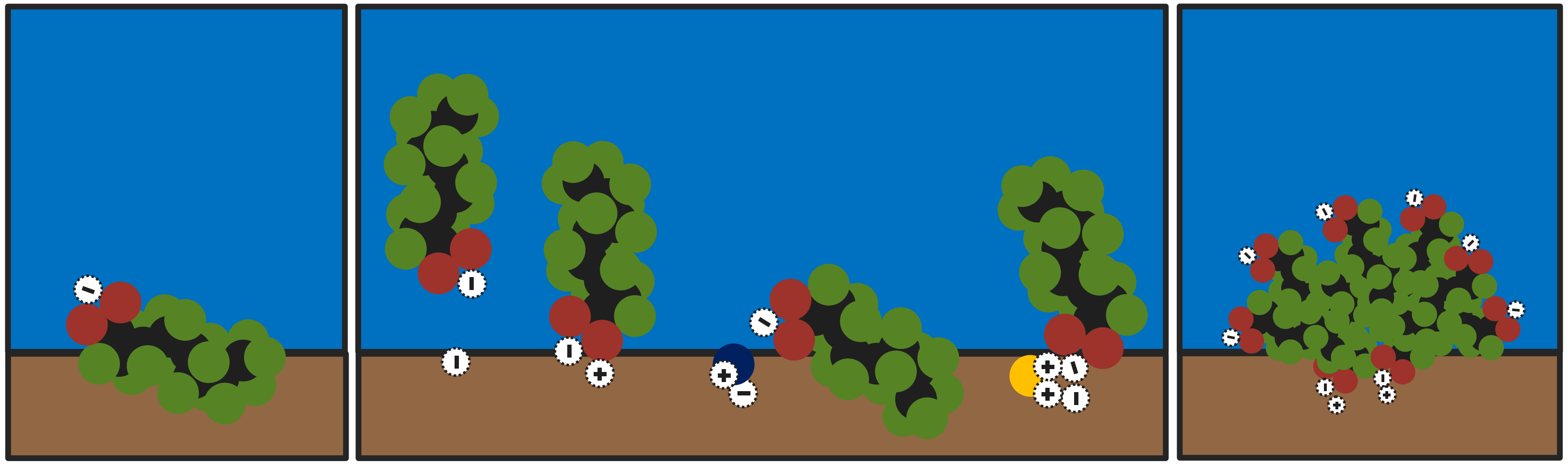
General Phase Partitioning

Simplified model

- Three soil phases
- Described with partition coefficients
- Steady-state, equilibrium

constant for known or assumed conditions

PFOA/PFOS Phase Partitioning



Hydrophobic sorption

Electrostatic interactions

Surfactant behavior (at higher conc.)

K_d and K_{oc} (K_d*f_{oc}) are aspirationally constant for known or assumed conditions

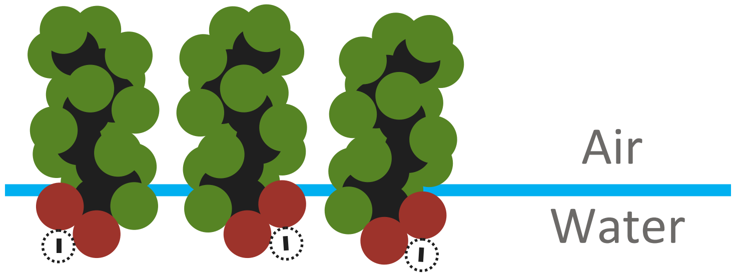
Rovero et al. (2021) on PFAS K_d/K_{oc} high variability, partly a function of:

- Adsorption v. Desorption
- Laboratory v. Field
- Soil cations, pH, etc.

For Discussion Purposes at July 15, 2026 CSSAB Meeting

Rovero, M., Cutt, D., Griffiths, R., Filipowicz, U., Mishkin, K., White, B., Goodrow, S. and Wilkin, R.T. (2021), Limitations of Current Approaches for Predicting Groundwater Vulnerability from PFAS Contamination in the Vadose Zone. Groundwater Monit R, 41: 62-75. https://doi.org/10.1111/gwmr.12485

PFOA/PFOS Phase Partitioning



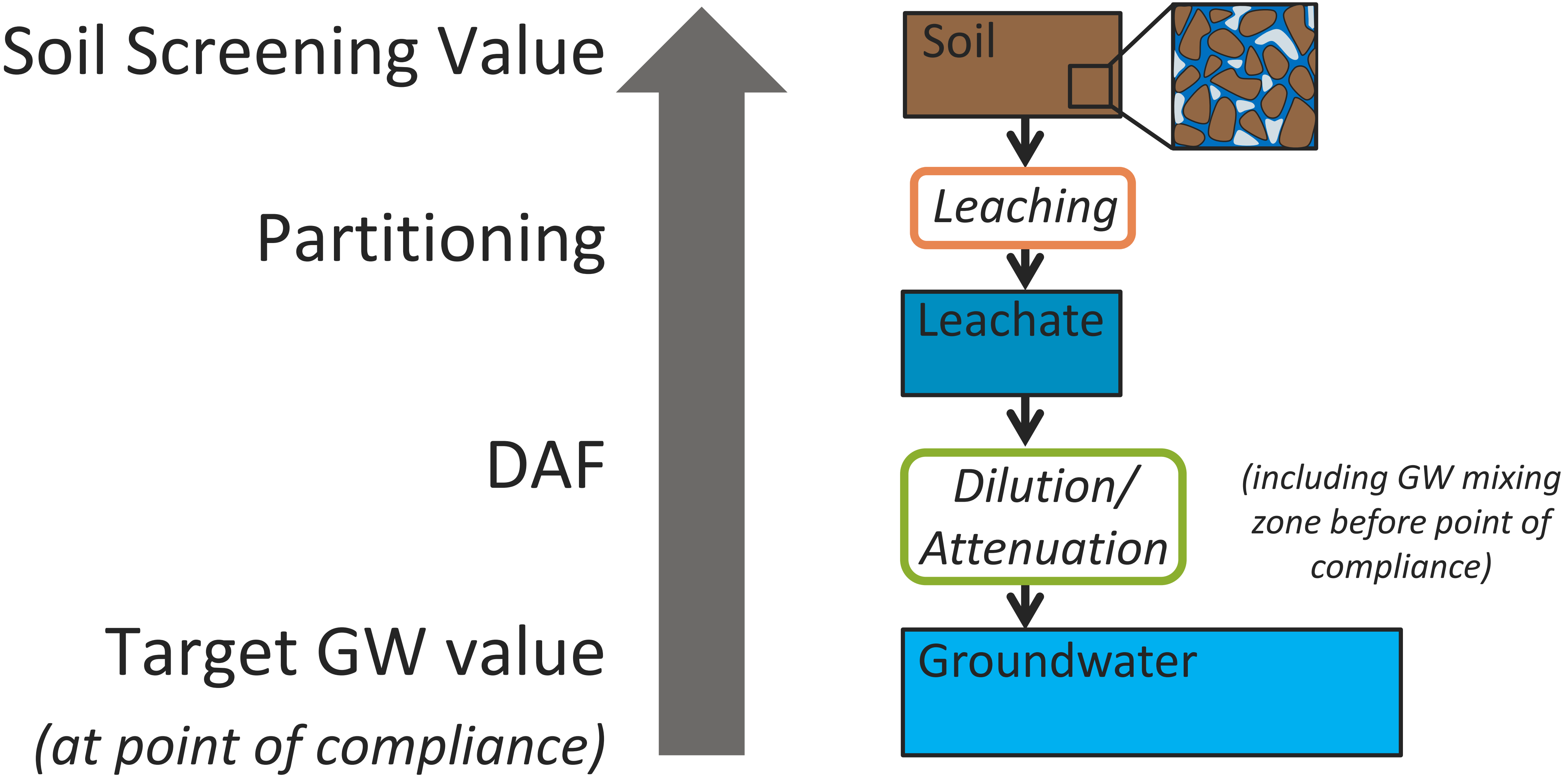
Brusseau et al. (2019)[1] and Guo et al. (2020)[2]

- Can be >80% total retention in vadose zone
- Greater retention in sand vs. finer-grains

For Discussion Purposes at July 15, 2026 CSSAB Meeting

1. Brusseau, Yan, Van Glubt, Wang, Chen, Lyu, Dungan, Carroll, Holguin. (2019). Water Research, 148 41-50: https://doi.org/10.1016/j.watres.2018.10.035
2. Guo, Zeng, and Brusseau. (2020). Water Resources Research, 57: https://doi.org/10.1029/2019WR026667

Soil Screening Value Calculation



MSC Soil-to-Groundwater Calculation

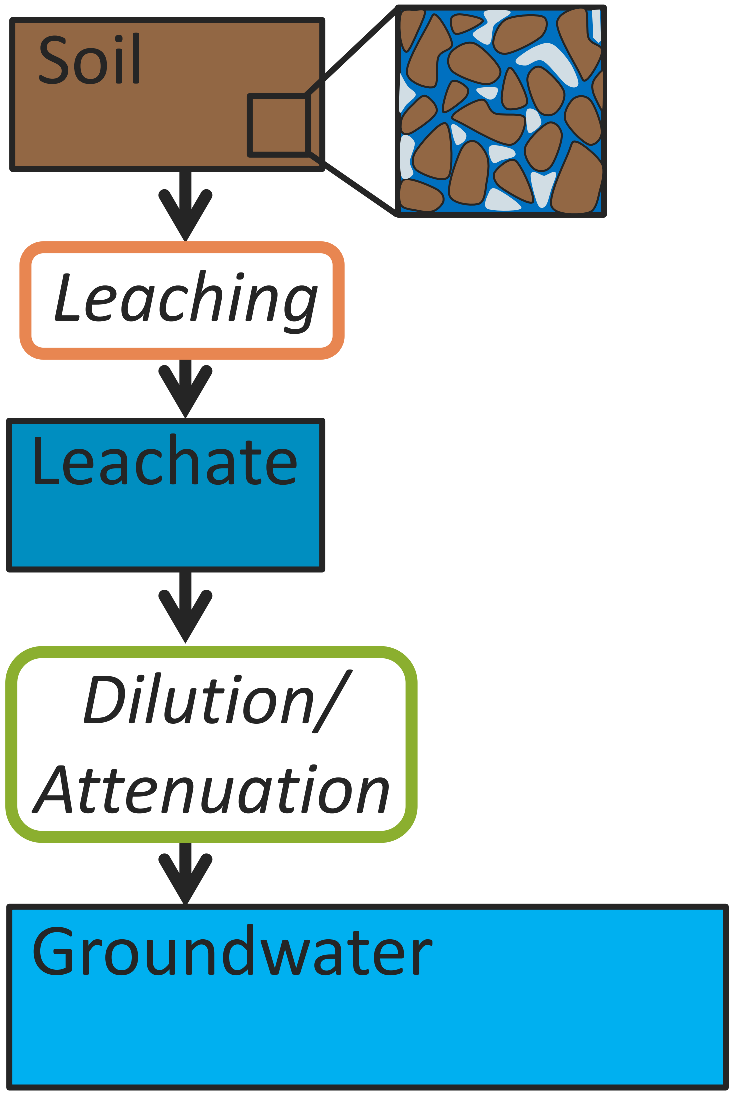
$$MSC_S$$

$$[(K_{oc} * f_{oc}) + \theta_w/\rho_b]$$

Currently does not include air-water interface term

$$DF$$

$$MSC_{GW}$$



§ 250.308(a)(2)(i) and (ii)

(i) For soil not in the zone of groundwater saturation, the generic value shall be calculated by the equation in paragraph (3).

(ii) For soil in the zone of groundwater saturation, the generic numeric value is 1/10th of the generic value calculated by the equation in paragraph (3).

(3): $MSC_S = MSC_{GW} \times [(K_{oc} * f_{oc}) + (\theta_w)/\rho_b] \times DF$

1/10th: $MSC_{SAT} = MSC_{GW} \times [(K_{oc} * f_{oc}) + (\theta_w)/\rho_b] \times DF/10$

PFAS-Adapted Generic Soil Screening Equations

Brusseau and Guo (2023) adapted USEPA SSL equation:

$$C_{soil} = C_{gw} \times \left[K_d + (\boldsymbol{K_{aw}A_{aw}} + \theta_w + \theta_a H)\frac{1}{\rho_b} \right] \times DAF$$

$$C_{soil} = C_{gw} \times [(K_{oc} * f_{oc}) + (\boldsymbol{K_{aw}A_{aw}} + \theta_w)/\rho_b] \times DAF$$

Adapted § 250.308(a)(3) MSC for soil to groundwater:

$$MSC_S = MSC_{GW} \times [(K_{oc} * f_{oc}) + (\boldsymbol{K_{aw}A_{aw}} + \theta_w)/\rho_b] \times DF$$

NEW

For Discussion Purposes at July 15, 2026 CSSAB Meeting

Brusseau, M.L. and Guo, B. (2023). Revising the EPA dilution-attenuation soil screening model for PFAS. Journal of Hazardous Materials Letters, 4, 100077.

Adapted Equation Special Data Needs

- K_{oc}
  - Chemical-specific
  - Assumed constant for given conditions
  - Already part of existing equation
  - Included in Appendix A Table 5A for PFOA, PFBS, and PFOS, consistent with USEPA RSL chemical parameters
  - Other PFAS K_{oc} values included in USEPA RSL chemical parameters
- K_{aw}
  - Chemical-specific
  - Assumed constant for given conditions
- A_{aw}
  - Not chemical-specific
  - Assumed constant for given conditions

Preliminary Example Calculation for PFOS

Brusseau and Guo (2023): PFOS K_{aw} ~ 0.12 cm^3/cm^2; Tucson, AZ, sand A_{aw} ~ 446 cm^2/cm^3

Adapted § 250.308(a)(2). MSC for soil to groundwater:

$$MSC_S = MSC_{GW} \times [(\boldsymbol{K_{oc} * f_{oc}}) + (\boldsymbol{K_{aw}A_{aw}} + \boldsymbol{\theta_w})/\rho_b] \times 100$$

$$MSC_S = 0.004\ \mu g/L \times [(\mathbf{372}(\frac{\boldsymbol{L}}{\boldsymbol{kg}}) * \mathbf{0.0025}) + (\mathbf{0.12*446} + \mathbf{0.2})/1.8\frac{kg}{L}] \times 100$$

$$MSC_S = 0.000004\ mg/L \times [\mathbf{0.930}\frac{\boldsymbol{L}}{\boldsymbol{kg}} + \mathbf{29.7}\frac{\boldsymbol{L}}{\boldsymbol{kg}} + \mathbf{0.111}\frac{\boldsymbol{L}}{\boldsymbol{kg}}] \times 100$$

PRELIMINARY EXAMPLE $MSC_S = 0.0123\ mg/kg$

For Discussion Purposes at July 15, 2026 CSSAB Meeting

Adapted § 250.308(a)(2)(i) and (ii)

(i) For soil not in the zone of groundwater saturation, the generic value shall be calculated by:

$$MSC_S = MSC_{GW} \times \left[(K_{oc} * f_{oc}) + \frac{\boldsymbol{K_{aw}A_{aw}} + \theta_w}{\rho_b} \right] \times DF$$

(ii) For soil in the zone of groundwater saturation, the generic numeric value calculated as below- <u>no proposed change to current equation</u>:

$$MSC_{SAT} = MSC_{GW} \times [(K_{oc} * f_{oc}) + (\theta_w)/\rho_b] \times DF/10$$

Includes 1/10th, but does not include air-water interface

Greater saturation (θ_w) not adjusted in current approach - protective bias.

Adapted § 250.308(c) Soil-to-Groundwater Pathway Soil Buffer Distances

$$\boldsymbol{C_{soil(it)}} = \boldsymbol{C_{soil(i(t-1))}} - \frac{(\boldsymbol{TI})(R)(\boldsymbol{C_{aq(i(t-1))}} - \boldsymbol{C_{aq(i+1)(t-1)}})}{(360)(DI)(\rho_b)}$$

$$\boldsymbol{TI} = (360)(DI)(\theta_w)/R$$

$$\boldsymbol{C_{aq(i(t-1))}} = \frac{(\rho_b)(C_{soil(i(t-1))})}{(K_d)(\rho_b) + \boldsymbol{K_{aw}A_{aw}} + \theta_w}$$

$$\boldsymbol{C_{aq(i+1)(t-1))}} = \frac{(\rho_b)(C_{soil(i+1)(t-1)})}{(K_d)(\rho_b) + \boldsymbol{K_{aw}A_{aw}} + \theta_w}$$

R = recharge rate of water infiltrating soil, DI = thickness of each layer I of soil

Demonstrations

- Example spreadsheet calculations
- PFAS-LEACH excel tool, highlight parameter selection
  - K_{oc}
  - K_{aw}
  - A_{aw}

From Brusseau and Guo (2023)

Table 1
Example Parameters and Calculated SSLs for PFOS and PFOA.

Parameter	PFOS Standard Model	PFOS Revised Model	PFOA Standard Model	PFOA Revised Model
Dilution Factor (DF)	20	20	20	20
Attenuation Factor (AF)	1	1	1	1
Dilution-Attenuation Factor (DAF)	20	20	20	20
Bulk density (ρ_b, g/cm^3)	1.5	1.5	1.5	1.5
Water content (θ_w, -)	0.2	0.2	0.2	0.2
Air content (θ_a, -)	0.2	0.2	0.2	0.2
Porosity (n, -)	0.4	0.4	0.4	0.4
Sorption coefficient (K_d, cm^3/g)[a]	2	2	1	1
Henry's Law constant (H, -)	0	0	0	0
Air-water interfacial adsorption coefficient (K_{aw}, cm)[b]	NA	0.12	NA	0.008
Air-water interfacial area (a_{aw}, cm^{-1})[c]	NA	446	NA	446
Distribution term (R_d, -)	16	283.6	8.5	26.3
Target groundwater concentration (C_{gw}, µg/L)[d]	0.1	0.1	0.1	0.1
Soil Screening Level (SSL, µg/kg)	4.3	75.6	2.3	7.0

[a] Measured values from (Brusseau et al., 2021)
[b] Measured values from (Costanza et al., 2019; Silva et al., 2019; Brusseau and Van Glubt, 2021)
[c] Measured value from (Guo et al., 2020)
[d] The target groundwater concentration employed is an arbitrary value used for illustration only

Calculation of MSCs w/ Air-Water Interface Coefficients

Parameter	Basis	Soil Values	PFOS	PFOA
DAF	PADEP Default	100	N/A	N/A
Bulk Density (ρb)	PADEP Default	1.8	N/A	N/A
Porosity (n)	PADEP Default	0.32	N/A	N/A
Water Content (θw)	PADEP Default	0.2	N/A	N/A
Air Content (θa)	PADEP Default	0.12	N/A	N/A
Sorption Coefficient (Kd)	Mark L. Brusseau, Bo Guo (2023)	N/A	2	1
Organic Carbon Partition Coefficient (Koc)	PADEP 2024 Proposed Rulemaking*	N/A	370	120
Fraction Organic Carbon (foc)	PADEP Default	0.0025	N/A	N/A
Henry's Law Constant (H)	PADEP Default	0	N/A	N/A
Air-Water Interfacial Adsorption Coefficient (cm) (Kaw)	Mark L. Brusseau, Bo Guo (2023)	N/A	0.12	0.008
Air-Water Interfacial Area (cm-1) (αaw)	Mark L. Brusseau, Bo Guo (2023)	446	N/A	N/A
Target Groundwater Concentration (ug/L) (MSC_{GW})	Proposed MSCs PADEP - Residential (2024)	N/A	0.004	0.004
Target Groundwater Concentration (mg/L) (MSC_{GW})	Proposed MSCs PADEP - Residential (2024)	N/A	0.000004	0.000004
Soil Screening Level (mg/kg) (MSC_S) - Koc Derived	PADEP Equation (**NO A/W PARTITIONING**): MSC_{GW} ((Koc * foc) + θw/ρb) DAF	N/A	0.0004	0.0002
Soil Screening Level (mg/kg) (MSC_S) - Koc Derived	Modified PADEP Equation: MSC_{GW} ((Koc * foc) + **(Kaw*αaw)** + θw/ρb) DAF	N/A	0.0123	0.0010

*Values recommended by USEPA Superfund program in May 2021 memo "Recommendations on the Use of Chronic or Subchronic Noncancer Values for Superfund Human Health Risk Assessments."

	PFOS	PFOA
2024 Res. Soil-to-Groundwater MSC, 100xMSC (µg/kg):	0.40	0.40
No Air-Water Partitioning, Soil-to-Groundwater MSC (µg/kg):	0.41	0.16
Air-Water Partitioning, Soil-to-Groundwater MSC (µg/kg):	12.3	0.96

Evaluation: Model Inputs

Soil-to-Groundwater Partitioning Equation is very sensitive to AWIA parameters.

- Is ***Aaw*** from 2023 research paper representative of Pennsylvania soil conditions?

Preliminary evaluation of model input bounds using predefined inputs from PFAS-LEACH Model.

- ***Aaw*** estimates from soil characteristics including <u>van Genuchten parameters*</u>
- ***Kaw*** estimates from chemical characteristics including <u>surface tension parameters</u>

PFAS-LEACH uses the widely used Rosetta soil model for calculating **Aaw.*

USDA: Rosetta can be used to estimate the following properties:
- Water retention parameters according to van Genuchten (1980)
- Saturated hydraulic conductivity
- Unsaturated hydraulic conductivity parameters according to van Genuchten (1980) and Mualem (1976)

Excel Tool for PFAS-LEACH Tiers 3 and 4 models

Version 1.0

① Soil Properties and Site Conditions			Parameter Values	Set Default Values
Depth to groundwater*	Z_w	cm	300	
Contaminated site area (or unit area)	A	m^2	2500	Soil Type
Temperature	T	°C	20.00	User defined
Net infiltration*	I_f	cm/yr	33.00	
Soil bulk density*	ρ_b	g/cm^3	1.80	
Saturated hydraulic conductivity	K_s	cm/day	13.47	
Residual water content	θ_r	cm^3/cm^3	0.080	
Saturated water content*	θ_s	cm^3/cm^3	0.320	
Median grain size	d_{50}	cm	0.009	
Organic carbon fraction	f_{oc}	%	0.25	
van Genuchten parameter	α	cm^{-1}	0.025	
van Genuchten parameter	n	(-)	1.36	
Longitudinal dispersivity*	α_L	cm	13.42	Estimate α_L
Water content*	θ	cm^3/cm^3	0.254	Estimate θ
Air–water interfacial area scaling factor	SF	(-)	4.1	Estimate SF
Air–water interfacial area*	A_{aw}	cm^2/cm^3	128.4	Estimate A_{aw}

② PFAS Properties			Parameter Values	
Surface tension parameter	a	mg/L	3.7	
Surface tension parameter	b	(-)	0.12	PFAS Type
Surface tension parameter	σ_0	dyn/cm	71.0	PFOS
Molar mass*	M	g/mol	500.13	
Molecular diffusion coefficient*	D_0	cm^2/s	5.40E-06	
Molar volume	V_m	cm^3/mol	271.81	
Organic carbon-water partition coefficient	K_{oc}	cm^3/g	649.4	
Solid–phase adsorption coefficient*	K_d	cm^3/g	0.30	Estimate K_d
Air–water interfacial adsorption coefficient*	K_{aw}	cm^3/cm^2	4.79E-02	Estimate K_{aw}

NOTE: Fs and α_s are only needed for using the advanced solver.

Instantaneous solid-phase sorption fraction*	F_s	(-)	0.50
Kinetic solid-phase sorption rate constant*	α_s	1/hour	1.00E-04

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Evaluation: Model Input (continued)

			PADEP Defaults
Depth to groundwater*	Zw	cm	300
Contaminated site area (or unit area)	A	m2	2500
Temperature	T	°C	20
Net infiltration*	If	cm/yr	33
Soil bulk density*	ρb	g/cm3	1.8
Saturated hydraulic conductivity	Ks	cm/day	13.47
Residual water content	θr	cm3/cm3	0.08
Saturated water content* (total porosity)	θs	cm3/cm3	0.32
Median grain size	d50	cm	0.0091
Organic carbon fraction	foc	%	0.25
van Genuchten parameter	α	cm-1	0.03
van Genuchten parameter	n	(-)	1.36
Longitudinal dispersivity*	αL	cm	13.42
Water content*	θ	cm3/cm3	0.25
Air–water interfacial area scaling factor	SF	(-)	4.07
Air–water interfacial area*	Aaw	cm2/cm3	128.36
PADEP VALUES for MSCs = MSC_{GW} ((K_{oc} * f_{oc}) + θ_w/ρ_b) DF			
Total soil porosity, ϑ = ϑa + ϑm	θ	*cm3/cm3*	*0.32*
Air-filled soil porosity	θa	*cm3/cm3*	*0.12*
Moisture-filled soil porosity	θw	*cm3/cm3*	*0.2*
Fraction of organic carbon in soil	foc	%	*0.25*
Dry bulk density of soil	ρb	*kg/L*	*1.8*
Recharge rate of water infiltrating soil	R	cm/yr	33.00

PFAS-LEACH and Rosetta Models were used to calculate ***Aaw*** for Act 2 soil type.

The results were ~30% the ***Aaw*** value used in the 2023 white paper: <u>more</u> conservative

USDA Soil Type	Aaw
SANDY CLAY	61.15
PADEP MSC VALUES	*128.36*
SILTY CLAY	266.39
SANDY CLAY LOAM	275.85
CLAY LOAM	370.05
SANDY LOAM	729.94
SAND	897.41
LOAM	953.54
LOAMY SAND	957.86
SILTY CLAY LOAM	1134.70
SILT LOAM	3157.76
SILT	3278.88

Preliminary Sensitivity Analysis

PFOS

Water Content (θw)	Organic Carbon Partition Coefficient (Koc)	Fraction Organic Carbon (foc)	Air-Water Interfacial Adsorption Coefficient (Kaw)	Air-Water Interfacial Area (αaw)

D

PFBA

Water Content (θw)		Organic Carbon Partition Coefficient (Koc)		Fraction Organic Carbon (foc)		Air-Water Interfacial Adsorption Coefficient (Kaw)			Air-Water Interfacial Area (αaw)		
Default Value:	0.2	Reference Value:	75.86	Default Value:	0.0025		Reference Value:	2.4E-05		Reference Value:	128.36
Test Value:	0.2	Test Value:	76	Test Value:	0.0025		Test Value:	2.4E-05		Test Value:	128.36
Ranges:	0.01 to 0.5	Ranges:	0.16 to 575	Ranges:	0.001 to 0.034	Ranges:	PUBLISHED/CALCULATED		Ranges:	PFAS LEACH	
0.01	0.689	0.1	3.96E-01	0.001	0.6604	PFAS-LEACH	2.40E-05	1.06E+00	SANDY CLAY	61.15	1.06E+00
0.02	0.709	0.2	3.97E-01	0.002	0.9259				~PADEP Defaults~	129.30	1.06E+00
0.04	0.748	0.4	3.98E-01	0.004	1.4569				SILTY CLAY	266.39	1.07E+00
0.08	0.825	0.8	4.02E-01	0.008	2.5190				SANDY CLAY LOAM	275.85	1.07E+00
0.16	0.981	1.6	4.09E-01	0.016	4.6430				CLAY LOAM	370.05	1.07E+00
0.32	1.292	3.2	4.23E-01	0.032	8.8912				SANDY LOAM	729.94	1.09E+00
0.64	1.914	6.4	4.51E-01						SAND	897.41	1.09E+00
		12.8	5.07E-01						LOAM	953.54	1.10E+00
		25.6	6.19E-01						LOAMY SAND	957.86	1.10E+00
		51.2	8.43E-01						SILTY CLAY LOAM	1134.70	1.11E+00
		102.4	1.29E+00						SILT LOAM	3157.76	1.20E+00
		204.8	2.19E+00						SILT	3278.88	1.21E+00
		409.6	3.98E+00								
		819.2	7.56E+00								

LONG CHAIN – C8

	PFOS	
100x MSC:	0.40	µg/kg
No AWIA MSC:	0.37	µg/kg
Default AWIA MSC:	3.84	µg/kg

INTERMEDIATE CHAIN – C6

	HFPO-DA (GenX)	
100x MSC:	1.00	µg/kg
No AWIA MSC:	1.02	µg/kg
Default AWIA MSC:	1.19	µg/kg

SHORT CHAIN – C4

	HFPO-DA (GenX)	
100x MSC:	3500.00	µg/kg
No AWIA MSC:	663.78	µg/kg
Default AWIA MSC:	1058.65	µg/kg

Preliminary Conclusions & Recommendations

In general, the lower the ***Kaw***, the more impact ***Koc*** will be to vadose zone F&T.

- Shorter chain PFAS – lower ***Kaw***, less air-water interface retention
- Longer chain PFAS – higher ***Kaw***, more air-water interface retention

Soil assumptions already used in Act 2 appear to be conservative using the AWIA partitioning equation.

Additional review recommended for:

- Determine upper and lower bounds for major factors contributing to AWIA partitioning (important for long chain):
  - ***Kaw***
  - Surface Tension Parameters
  - ***Aaw***
- Are EPA RSL values for ***Koc*** appropriate (important for short chain)?
- Is the Rosetta model acceptable for Van Genuchten parameter estimates for ***Aaw*** for Pennsylvania soil assumptions?

Groundwater/Surface Water Act 2 F&T Tools

Fate and Transport Tools Referenced in TGM Section III.A:

- **Quick Domenico (QD)** – Groundwater transport model with one-dimensional advection, three-dimensional dispersion – no proposed revisions to equations since saturated
- **SWLOAD** – Modification of QD to include mass loading to surface water - – no proposed revisions to equations since saturated
  - For compounds that react with organic carbon
  - 1st order decay is considered.
    - The first order decay constant (lambda) can be set to zero where the biodegradability of the compound or its decay rate is questionable. Currently being discussed by Workgroup for PFAS.
  - Does not consider the transformations
  - Considers no reaction between compounds
  - Assumes a spatially finite, non-decaying source (source concentration is constant).
- **Toxics Management Spreadsheet (TMS):** Used to determine water quality-based effluent limitations. Used in Act 2 to determine in-stream concentrations based on a mixing model.
  - Includes a first-order decay component. Set to zero for unknown or non-decaying substances.

Groundwater/Surface Water Act 2 F&T Tools

- **QD/SWLOAD** model

Domenico equation:

$$\frac{\partial}{\partial t}(n_e C + \rho S) = \frac{\partial}{\partial x}\left(n_e D_x \frac{\partial C}{\partial x} - qC\right) + n_e D_y \frac{\partial^2 C}{\partial y^2} + n_e D_z \frac{\partial^2 C}{\partial z^2} - \lambda_w n_e C - \lambda_s \rho S$$

where:

Table A1.1.

Symbol	Definition	Units
C	solute concentration	$M\ L^{-3}$
S	adsorbed concentration	$M\ M^{-1}$
n_e	effective porosity	$L^3\ L^{-3}$
ρ	bulk density	$M\ L^{-3}$
D_i	coefficients of dispersion	$L^2\ T^{-1}$
q	groundwater flux (Darcy velocity)	$L\ T^{-1}$
λ_w	water decay coefficient	T^{-1}
λ_s	soil decay coefficient	T^{-1}
x	longitudinal horizontal distance	L
y	transverse horizontal distance	L
z	downward vertical distance	L
t	time	T

M: mass, L: length, T: time

Adsorption (***S***) is a linear equation, like the soil SSL equation:

$$S = K_d * C$$

where $K_d = K_{oc} * f_{oc}$

And water decay coeff. (**λw**)= soil decay coeff. (**λs**) = **λ**

The transport equation is then expressed as:

$$\frac{\partial C}{\partial t} = \frac{\alpha_x v}{R}\frac{\partial^2 C}{\partial x^2} + \frac{\alpha_y v}{R}\frac{\partial^2 C}{\partial y^2} + \frac{\alpha_z v}{R}\frac{\partial^2 C}{\partial z^2} - \frac{v}{R}\frac{\partial C}{\partial x} - \lambda C = 0 \qquad \text{(A1-2)}$$

where:

Table A1.2.

Symbol	Definition	Expression	Units
R	retardation	$1 + \frac{\rho K_d}{n_e}$	—
α_i	dispersivity	D_i/v	L
v	interstitial groundwater velocity	q/n_e	$L\ T^{-1}$

The equation for ***R*** could be modified to include A_{aw} * K_{aw} partitioning, like for vadose zone modeling, but if we assume there is no unsaturated pore space: $K_{aw}A_{aw} = 0$

Groundwater/Surface Water Act 2 F&T Tools

- **TMS** model mixing equation:

$$C_{sw} = \frac{(Q_{gw} * C_{gw}) + (Q_{sw} * Y_c * C_{bsw})}{(Q_{sw} * Y_c) + Q_{gw}} \Longrightarrow C_{gw} = C_x + \frac{Y_c * Q_{sw} * (C_x - C_{bsw})}{Q_{gw}}$$

Where:
C_{sw} = Concentration in surface water
Q_{gw} = groundwater flow discharging to surface water
Q_{sw} = quantity surface water flow at discharge point
C_{gw} = concentration of substance discharging to surface water from groundwater
Y_c = Model mixing factor

And, **C_x** is the water quality objective

Assumes homogenous mixing within the stream at some point downstream of the point source discharge.

Next Steps for Generic Soil to Groundwater Equation

- Subject matter expert review of input of key terms to

$$MSC_S = MSC_{GW} \times [(\boldsymbol{K_{oc}} * \boldsymbol{f_{oc}}) + (\boldsymbol{K_{aw}A_{aw}} + \boldsymbol{\theta_w})/\rho_b] \times 100$$

- PFAS expertise to review the parameters proposed to be used for the PFAS compounds for the K_{aw} term and use of EPA RSL value for K_{oc}
  - CSSAB PFAS Workgroup member
  - External PFAS subject matter expert
- Soil mechanics/PA geology expertise to review input parameters for A_{aw}.
  - CSSAB PFAS Workgroup member (PG)
  - PADEP (PG)

Overview of Soil to GW equations in other States/Federally

- 14 states have soil to groundwater equations referenced for PFAS.
  - Many of these states reference the equations in the EPA's RSL Soil Screening Guidance, which does not have modification for PFAS
  - A few states have taken a different approach
    - NH – statewide soil sampling and modeling
    - NJ – statewide soil sampling and SPLP leachate results used to estimate the sample-specific soil-water partitioning coefficients (Kd values)
    - TX – does not include modifications in Tier 1 PCLs, but does recognize models with revisions accounting for air-water interface in site specific calculations
- EPA
  - EPA RSL calculator includes default partition coefficient (i.e., Kd, KOC) values for PFAS and allows for custom or site-specific values to be used for derivation of screening levels (U.S. EPA, 2022b)
  - EPA not modified the RSL Soil Screening Guidance
  - 2025 Guidance [1] allows for literature, model and site specific modifications to Kd value

1- Practical Groundwater Science Guides Per- and Polyfluoroalkyl Substances (PFAS), EPA 600/R-25/153 I July 2025 I www.epa.gov/research

CSSAB PFAS Workgroup Schedule

- July to September – Finalize input values for soil to groundwater equation/F&T models. Complete sensitivity testing of potential values.
- Update of CSSAB PFAS Workgroup Progress at October 21, 2026 CSSAB meeting
- Draft document by January 2027 (estimated date)
- Final document by March 2027 (estimated date)