Soil-to-Groundwater Leaching Approaches

Georgia Brownfield Association (GBA)
Leaching Workshop
February 28, 2020

VATTEN

Presentation Overview

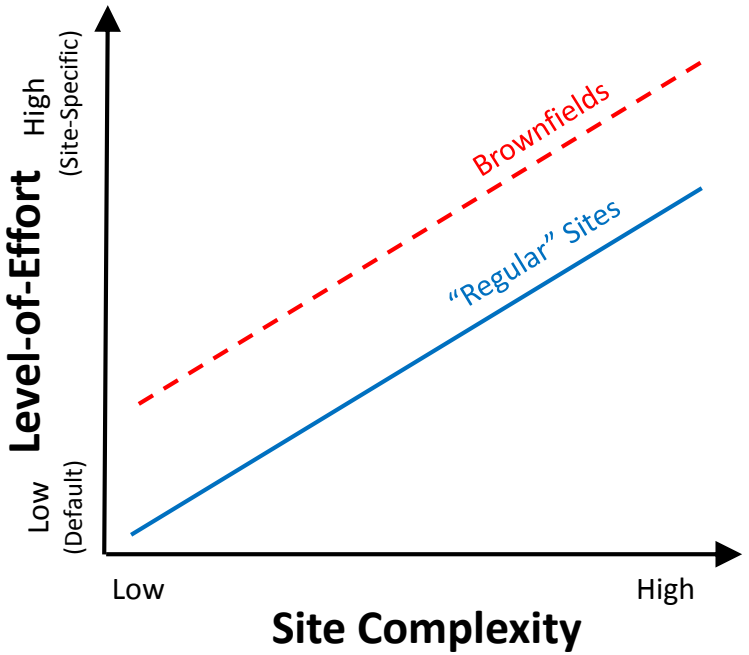
1. Introduction and Background
2. Five Leaching Assessment Approaches
3. Potential Modifying Factors
4. Case Studies (Len Diprima, United Consulting)

Leaching Introduction

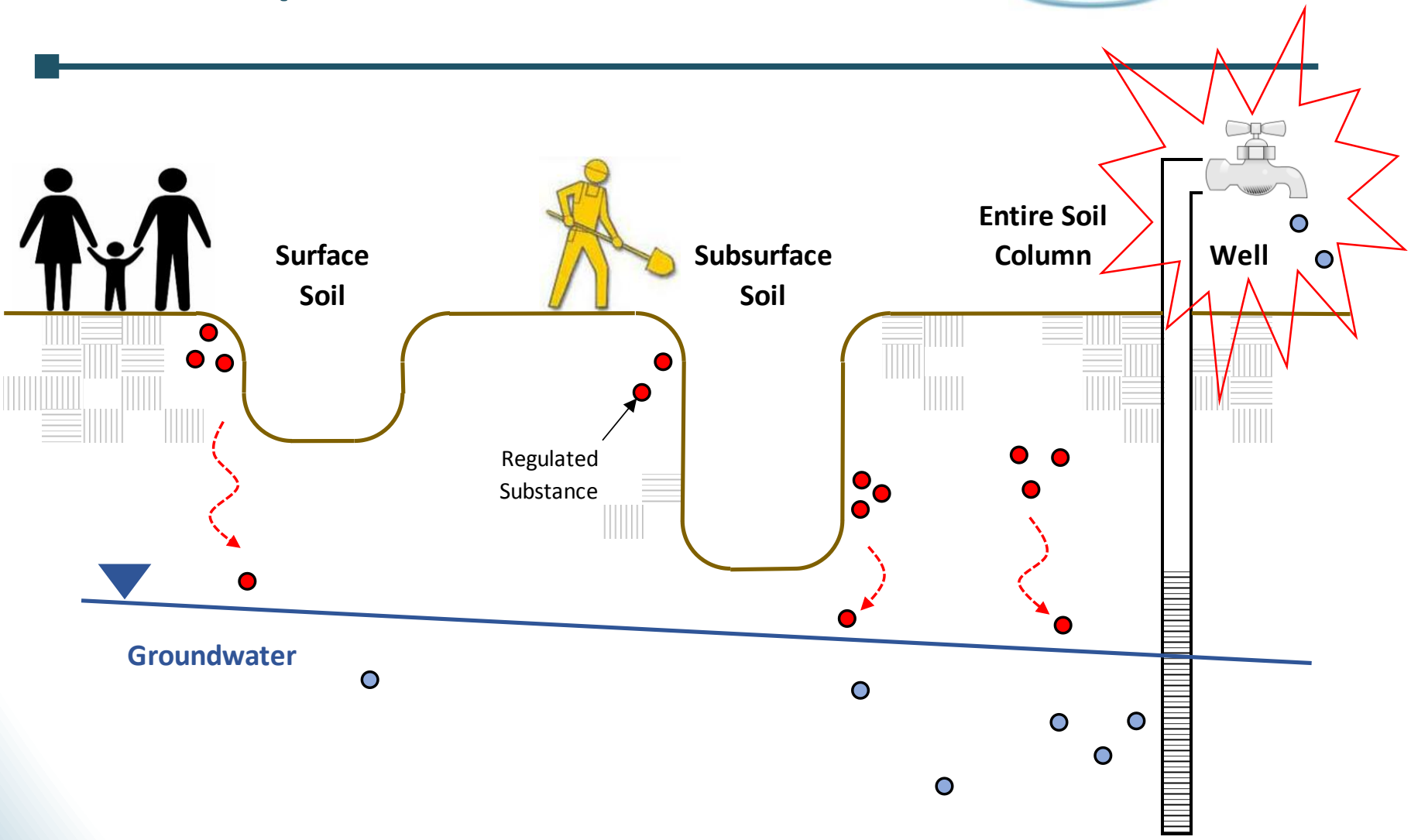
- Assessing Threats from Drinking Water
  - Containing Regulated Substances
  - That Have Leached From Soil and
  - Migrated in Groundwater
- Leaching Assessment Process Has Broad Applicability
  - Brownfield Act
  - Hazardous Site Response Act (HSRA)
  - Voluntary Remediation Program (VRP)
  - Hazardous Waste Management Act
- Field Sampling and Testing
  - Appropriate Number of Representative Soil and/or Groundwater Samples at Sufficient Times and Locations

Introduction - Continued

- Lab Testing
  - Total and/or Leachate Levels
- Range of Assessment Approaches
  - Default or Site-Specific
- Verify Underlying Assumptions
- Level-of-Effort Should Match Site Complexity

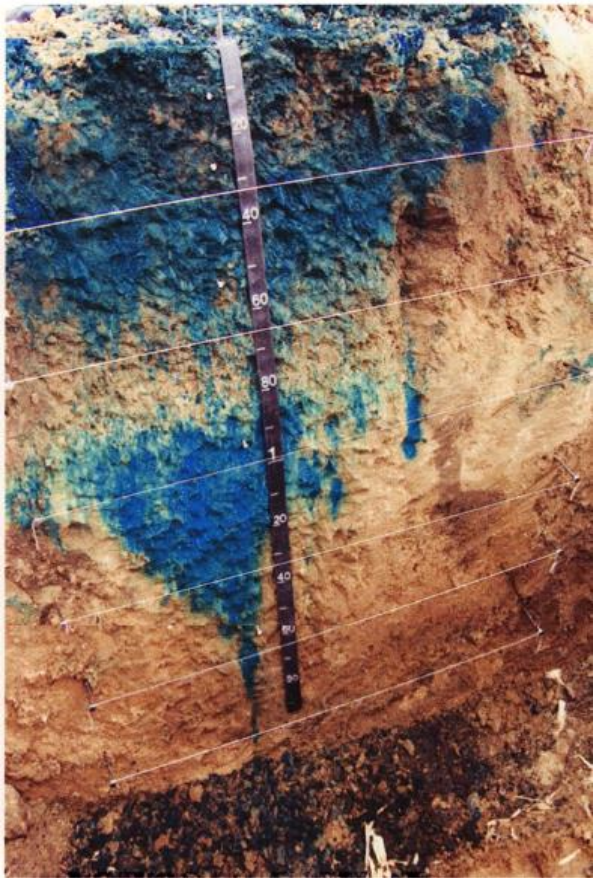


Conceptual Site Model



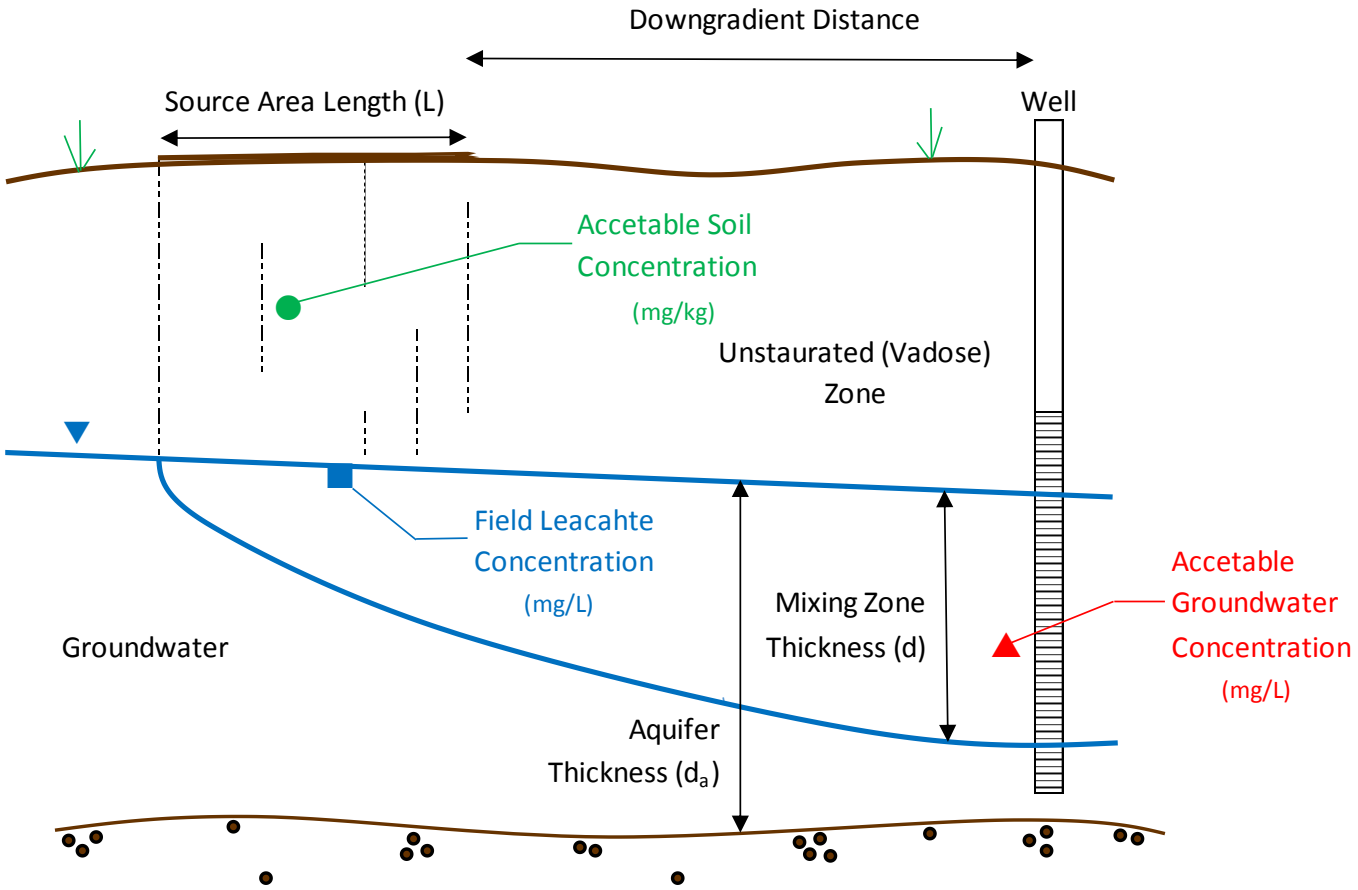
Improvement Opportunities
Recommendations from GaEPD

- Failure to Address Groundwater Protection via Soil Leaching
  - Improper Coefficient Calculations (K_d)
  - Coefficients from Improper Reference
  - Incorrect Dilution Attenuation Factor (DAF)
  - Using Incorrect Organic Carbon Content (f_{oc})



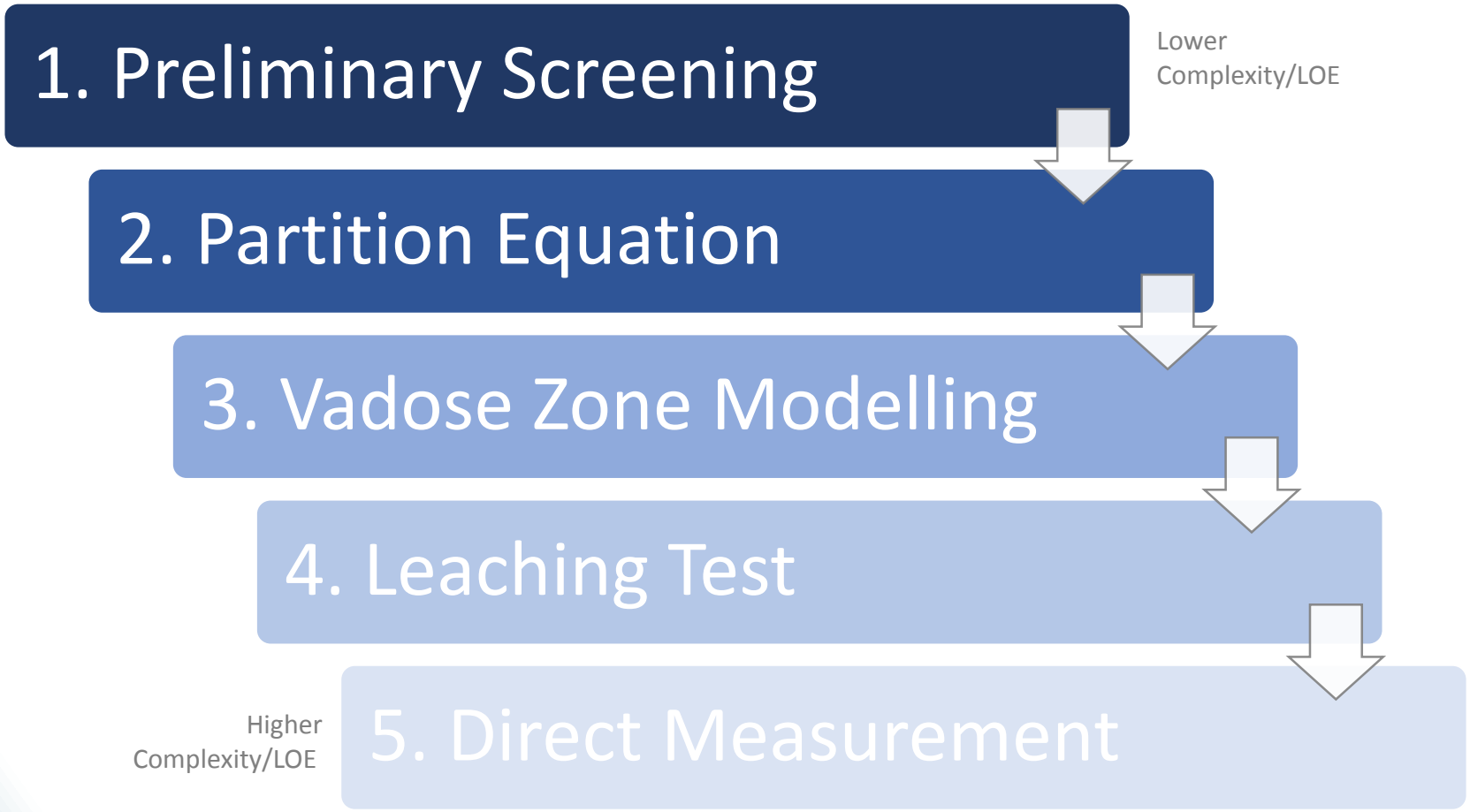
Source: Sophocleous *et al.*, 2006

Soil-to-Groundwater Pathway



Source: Leach GBA 2019-06-07.xls

Assessment Approaches



1. Preliminary Screening Approach

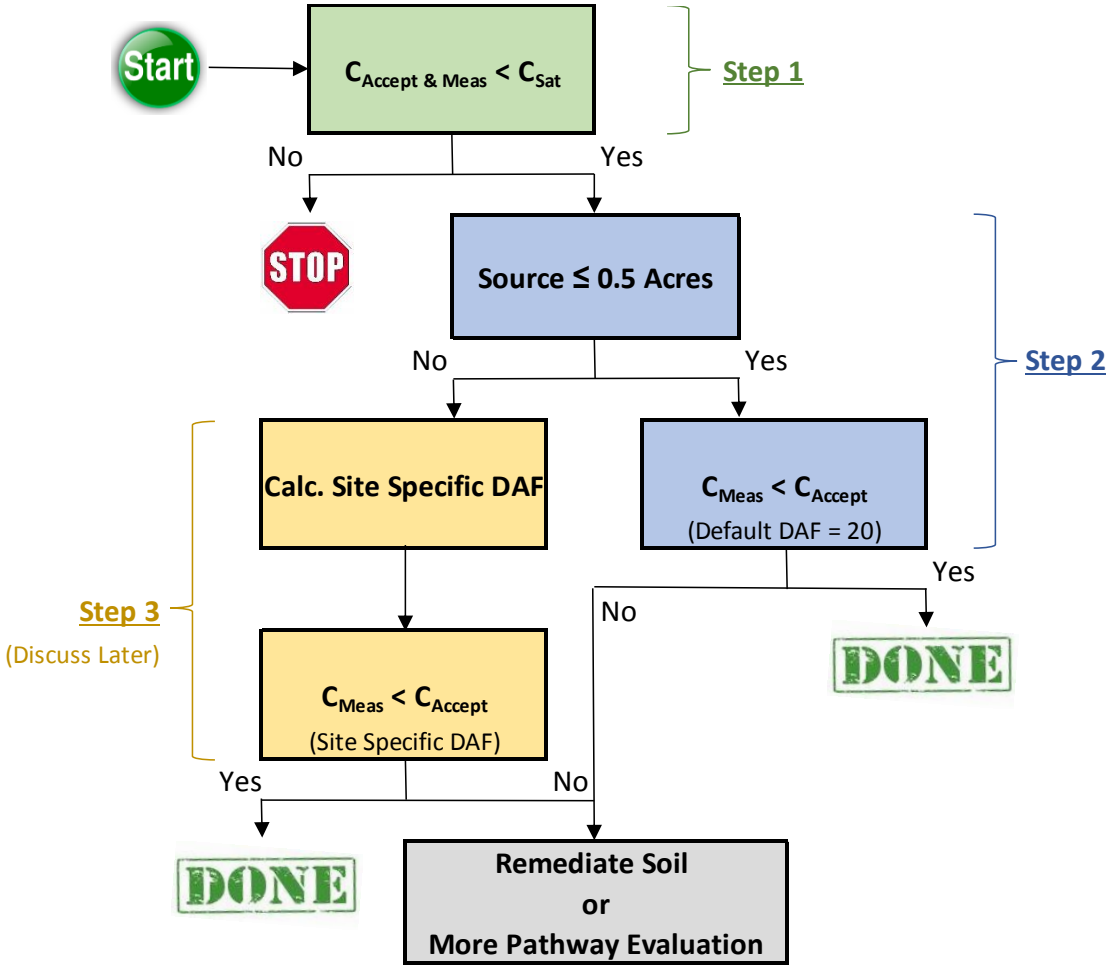
GBA Leaching Workshop

February 28, 2020

Preliminary Screening Approach

- Compare Measured Soil Concentrations to Pre-Calculated Acceptable Screening Levels
- GaEPD has Default "Look-up" Tables of Screening Levels
  - USEPA has Similar "Look-up" Tables
    - Regional Screening Levels or RSLs
- Use for Small Sites
  - Less Than or Equal to 0.5 Acres
  - Similar to Average Residential Lot
- Use for Single Regulated Substance

Flow Chart for Screening



Type 3 RRS "Look-up" Table

		Groundwater		Soil								
Regulated Substance	CAS	GW Type 3 RRS (mg/kg)	Basis	Risk-Based Soil Concentration for Default Non-Residential Direct Contact CR=1E-5, HQ=1 (mg/kg)	Risk Basis	Risk-Based Soil Concentration for Default Excavation Worker CR=1E-5, HQ=1 (mg/kg)	Risk Basis	Partition Equation DAF=20 (mg/kg)	Appendix I Soil Notification Concentration (mg/kg)	Final Default Soil Concentration for Protection of GW (mg/kg)	Type 3 RRS Surface Soil < 1 ft bgs (mg/kg)	Type 3 RRS Subsurface Soil > 1 ft bgs (mg/kg)
Acenaphthene	83-32-9	4.55E+00	nc	4.52E+04	nc	4.79E+04	nc	9.33E+02	3.00E+02	9.33E+02	9.33E+02	9.33E+02
Acetone	67-64-1	7.56E+01	nc	6.70E+05	nc	1.96E+05	nc	3.10E+02	2.74E+00	3.10E+02	3.10E+02	3.10E+02
Acrylonitrile	107-13-1	2.26E-03	ca	1.13E+01	ca	1.00E+01	nc	9.83E-03	1.37E+00	1.37E+00	1.37E+00	1.37E+00
Aldicarb	116-06-3	3.00E-03	mcl	8.21E+02	nc	2.57E+02	nc	1.50E-02	DL(P)	1.50E-02	1.50E-02	1.50E-02
Aldrin	309-00-2	3.97E-05	ca	1.84E+00	ca	1.36E+01	nc	1.30E-01	6.60E-01	6.60E-01	6.60E-01	6.60E-01
Antimony (metallic)	7440-36-0	6.00E-03	mcl	4.67E+02	nc	1.36E+02	nc	5.42E+00	10/BG	10/BG	10/BG	10/BG
Arsenic, Inorganic	7440-38-2	1.00E-02	mcl	3.00E+01	ca	1.46E+02	nc	5.84E+00	4.10E+01	4.10E+01	3.00E+01	4.10E+01
Barium	7440-39-3	2.00E+00	mcl	2.17E+05	nc	6.77E+04	nc	1.65E+03	500/BG	1.65E+03	1.65E+03	1.65E+03
Benz[a]anthracene	56-55-3	3.63E-03	ca	2.06E+02	ca	3.20E+03	ca	2.57E+01	5.00E+00	2.57E+01	2.57E+01	2.57E+01
Benzene	71-43-2	5.00E-03	mcl	5.08E+01	ca	1.76E+02	nc	5.11E-02	2.00E-02	5.11E-02	5.11E-02	5.11E-02
Benzo[a]pyrene	50-32-8	2.00E-04	mcl	2.11E+01	ca	7.14E+01	nc	4.70E+00	1.64E+00	4.70E+00	4.70E+00	4.70E+00
Benzo[b]fluoranthene	205-99-2	3.27E-02	ca	2.11E+02	ca	3.36E+03	ca	7.84E+02	5.00E+00	7.84E+02	2.11E+02	7.84E+02
Benzo[k]fluoranthene	207-08-9	3.27E-01	ca	2.11E+03	ca	3.36E+04	ca	7.69E+03	5.00E+00	7.69E+03	2.11E+03	7.69E+03
Benzyl Chloride	100-44-7	3.93E-03	ca	4.79E+01	ca	6.08E+01	nc	8.60E-02	1.05E+00	1.05E+00	1.05E+00	1.05E+00
Beryllium and compounds	7440-41-7	4.00E-03	mcl	2.29E+03	nc	1.67E+03	nc	6.32E+01	3.00/BG	6.32E+01	6.32E+01	6.32E+01
Bis[2-ethylhexyl]phthalate	117-81-7	6.00E-03	mcl	1.64E+03	ca	2.57E+04	nc	2.87E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01
Bromodichloromethane	75-27-4	8.00E-02	mcl	1.28E+01	ca	5.09E+01	nc	4.34E-01	1.18E+00	1.18E+00	1.18E+00	1.18E+00
Bromoform	75-25-2	8.00E-02	mcl	8.57E+02	ca	7.15E+03	ca	4.25E-01	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Bromomethane	74-83-9	3.45E-02	nc	3.01E+01	nc	8.71E+01	nc	1.74E-01	8.00E-01	8.00E-01	8.00E-01	8.00E-01
Butyl Benzyl Phthalate	85-68-7	1.07E+00	ca	1.21E+04	ca	1.90E+05	ca	3.11E+02	5.00E+01	3.11E+02	3.11E+02	3.11E+02
Cadmium (Diet)	7440-43-9	5.00E-03	mcl	9.82E+02	nc	1.50E+02	nc	7.52E+00	3.90E+01	3.90E+01	3.90E+01	3.90E+01
Carbaryl	63-25-2	1.13E+01	nc	8.21E+04	nc	2.57E+04	nc	2.06E+02	1/BG	2.06E+02	2.06E+02	2.06E+02
Carbofuran	1563-66-2	4.00E-02	mcl	4.10E+03	nc	1.28E+03	nc	3.12E-01	8.00E-01	8.00E-01	8.00E-01	8.00E-01
Carbon Disulfide	75-15-0	3.96E+00	nc	3.47E+03	nc	5.28E+02	nc	2.33E+01	DL(P)/BG	2.33E+01	2.33E+01	2.33E+01
Carbon Tetrachloride	56-23-5	5.00E-03	mcl	2.87E+01	ca	1.72E+02	nc	3.86E-02	1.70E-01	1.70E-01	1.70E-01	1.70E-01
Chlordecone (Kepone)	143-50-0	2.21E-04	ca	2.30E+00	ca	3.61E+01	ca	1.56E-01	1.00E+01	1.00E+01	2.30E+00	1.00E+01
Chlorobenzene	108-90-7	1.00E-01	mcl	1.33E+03	nc	1.94E+03	nc	1.36E+00	4.18E+00	4.18E+00	4.18E+00	4.18E+00
Chloroform	67-66-3	8.00E-02	mcl	1.38E+01	ca	1.04E+02	ca	4.43E-01	6.80E-01	6.80E-01	6.80E-01	6.80E-01
Chloromethane	74-87-3	7.88E-01	nc	4.63E+02	nc	2.31E+03	nc	4.06E+00	4.00E-02	4.06E+00	4.06E+00	4.06E+00
Chlorophenol, 2-	95-57-8	5.60E-01	nc	5.84E+03	nc	2.72E+03	nc	1.09E+01	6.80E-01	1.09E+01	1.09E+01	1.09E+01
Chlorpyrifos	2921-88-2	7.32E-02	nc	8.21E+02	nc	7.71E+02	nc	2.16E+01	1/BG	2.16E+01	2.16E+01	2.16E+01
Chromium, Total	7440-47-3	1.00E-01	mcl	---	CrT	---	CrT	---	1.20E+03	1.20E+03	1.20E+03	1.20E+03
Chrysene	218-01-9	3.27E+00	ca	2.11E+04	ca	3.36E+05	ca	2.36E+04	5.00E+00	2.36E+04	2.11E+04	2.36E+04
Copper	7440-50-8	1.30E+00	mcl	4.67E+04	nc	3.39E+03	nc	9.15E+02	1.50E+03	1.50E+03	1.50E+03	1.50E+03
Cresols	1319-77-3	1.03E+01	nc	8.21E+04	nc	2.57E+04	nc	1.68E+02	3.80E+00	1.68E+02	1.68E+02	1.68E+02

Source: https://epd.georgia.gov/comparison-existing-contamination-risk-reduction-standards-391-3-19-07

Version 10/12/18

Using "Look-up" Table

Regulated Substance	Soil Saturation (C_{sat})	Non-Residential (surface soil)	Excavation Worker (subsurface soil)	Protect Groundwater (all soil)	Type 3 RRS (surface Soil)	Type 3 RRS (subsurface Soil)	Drinking Water (ug/L)[c]
Volatile Organic Compounds							
Benzene	1,820	50.8	176	0.0511	0.0511 ▼	0.0511 ▼	5
Chloroform	2,540	13.8	104	0.68	0.68 ▼	0.68 ▼	80
Trichloroethylene	692	18.7	2.84	0.13	0.13 ▼	0.13 ▼	5
Vinyl Chloride	3,920	16.8	45.9	0.04	0.04 ▼	0.04 ▼	2
Semi-Volatile Organic Compounds							
Benzo[a]pyrene	- - -	21.1	71.4	4.7	4.7 ▼	4.7 ▼	0.2
Benzo[b]fluoranthene	- - -	***211***	3,360	784	211■	784 ▼	32.7[d]
DDT	- - -	85.3	155	64.9	64.9 ▼	64.9 ▼	9.62[d]
PCBs ("high risk")[a]	- - -	9.42	138	1.56	1.56 ▼	1.56 ▼	0.5
Inorganics							
Arsenic	- - -	***30***	146	41	30 ■	41▼	10
Cadmium	- - -	982	150	39	39 ▼	39 ▼	5
Lead[b]	- - -	***400***	5,140	400	400 ■	400 ■	15
Mercury	- - -	45.6	***6.82***	17	17 ▼	6.82■	2

Unit of measure = milligrams per kilogram (mg/kg), ug/L = micrograms per liter

(a) = For other Aroclors or congeners screening levels may be higher or lower, (b) = See Rule 391-3-19-.07(8)(d)(4)

(c) = Maximum contaminant level (MCL), treatment technique or risk-based, (d) = GaEPD risk-based screening level at target risk of 10^{-5}

2. Partition Equation Approach

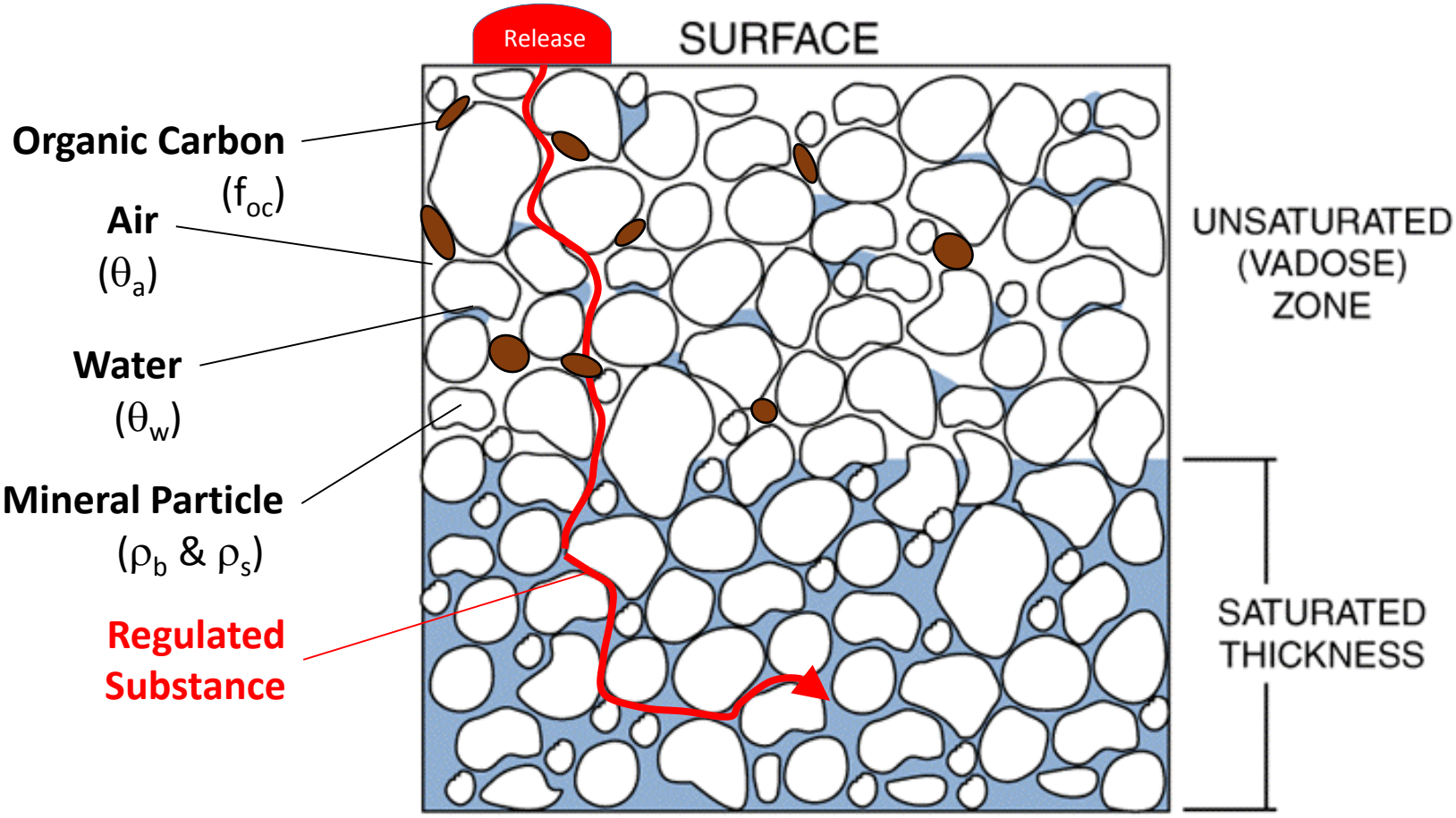
GBA Leaching Workshop

February 28, 2020

Partition Equation Approach

- Compare Measured Soil Concentrations to Screening Levels Calculated from Partition Equation
- Depends on Several
  - Soil Parameters
  - Chemical-Specific Factors
- Default/Site-Specific Factors
  - Soil Parameters
  - Soil-Water Partition Coefficient (K_d)
    - Leaching Test
    - Ionizing Organic and Inorganic Substances

Leaching Through Soil



After: Buddemeier, 2000

Simple Partition Equation

$$C_{Accept} = C_{Fld\ Leach}\left[K_d + \frac{(\theta_w + \theta_a * H')}{\rho_b}\right]$$

Where:

C_{Accept} = Acceptable soil concentration (mg/kg)

$C_{Fld\ Leach}$ = Acceptable field leachate concentration in groundwater immediately beneath source area (mg/L)

K_d = Soil-water partition coefficient (*e.g.*, organics), $K_{oc} * f_{oc}$ (L/kg)

H' = Dimensionless Henry's law constant (unitless) ←Chemical-specific

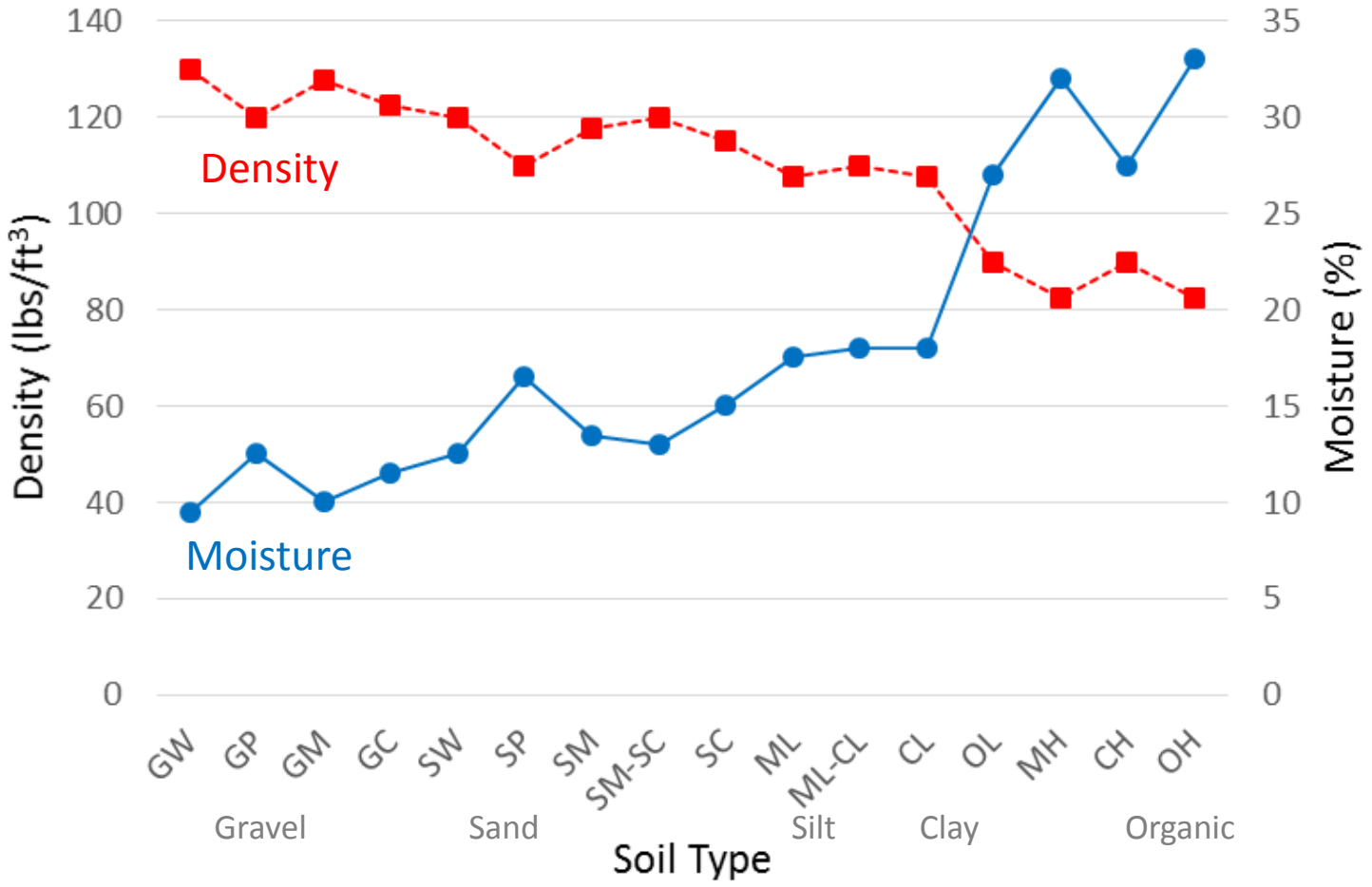
θ_w = Water-filled soil porosity (L_{water}/L_{soil}, default 0.3)

θ_a = Air-filled soil porosity, n - θ_w (L_{air}/L_{soil}, default 0.13) ←Soil-specific

ρ_b = Dry soil bulk density (kg/L, default 1.5)

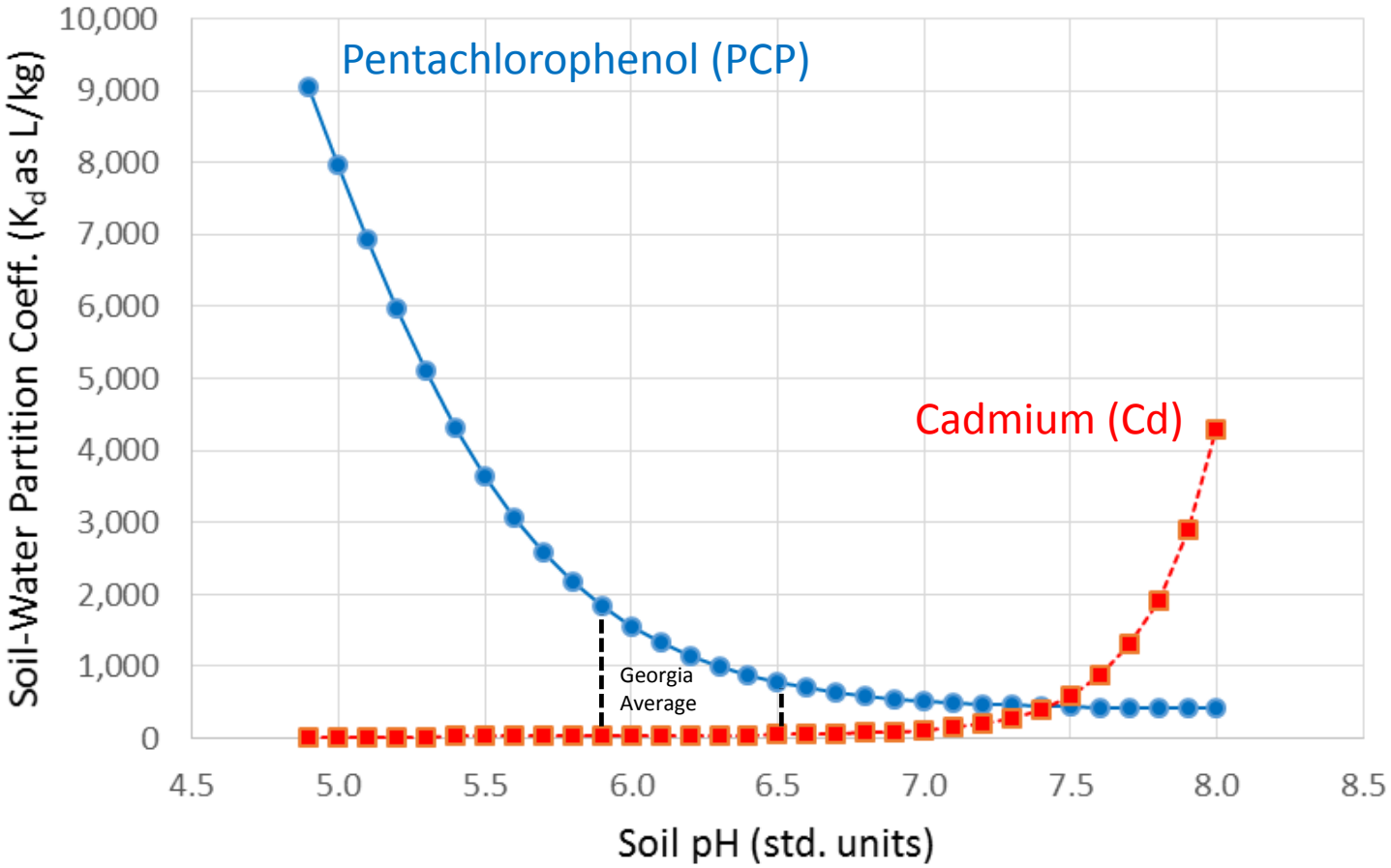
Source: USEPA, 11996; Eq. No. 10, page 29

Site-Specific Soil Values



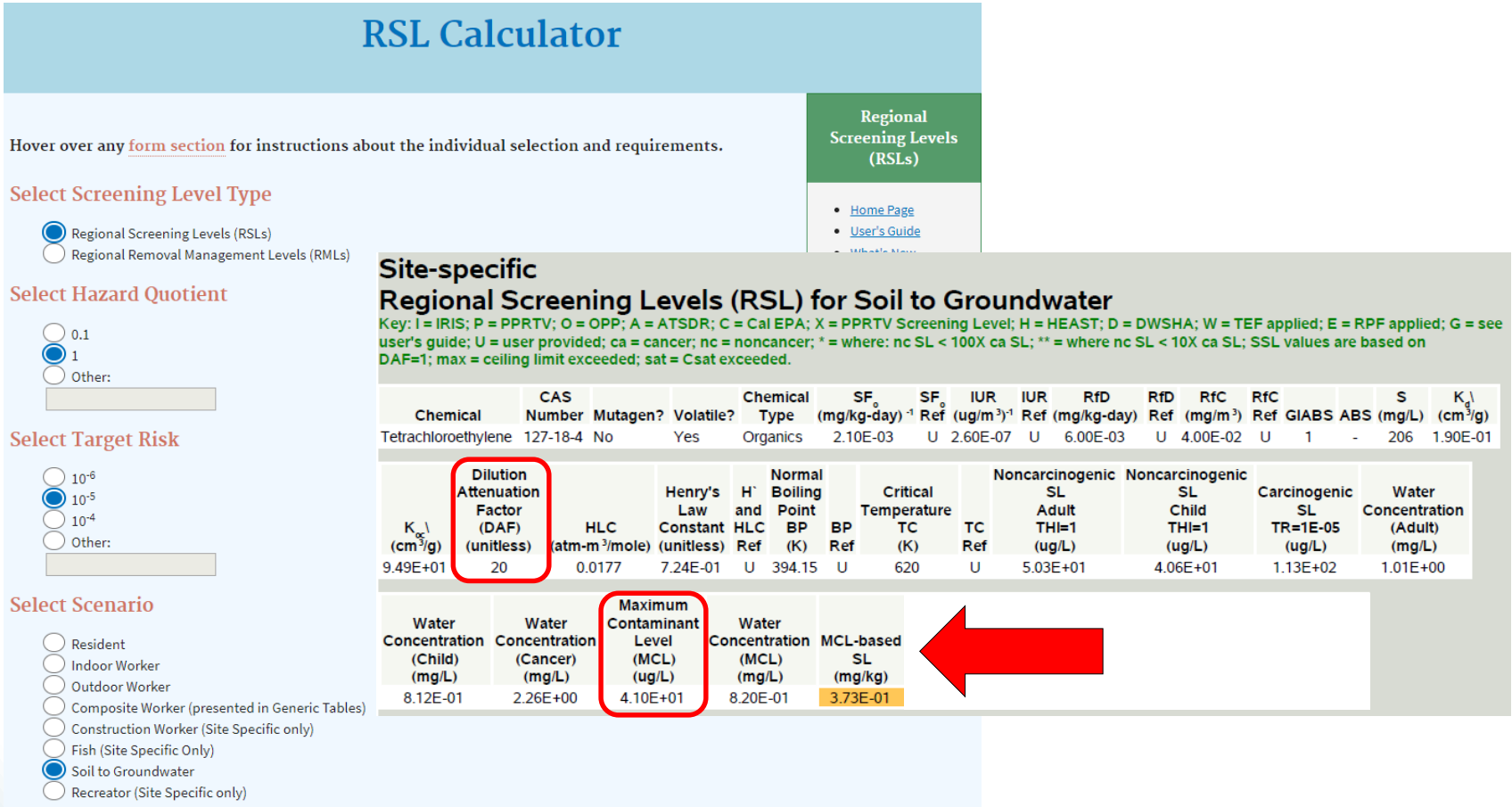
Ionizing Organics & Inorganics

Using USEPA "Look-up" Tables



Source: USEPA, 2002; Exhibits C-2 and C-4

USEPA RSL Calculator



RSL Calculator

Hover over any form section for instructions about the individual selection and requirements.

Regional Screening Levels (RSLs)

- Home Page
- User's Guide

Select Screening Level Type

- (●) Regional Screening Levels (RSLs)
- ( ) Regional Removal Management Levels (RMLs)

Select Hazard Quotient

- ( ) 0.1
- (●) 1
- ( ) Other:

Select Target Risk

- ( ) 10^{-6}
- (●) 10^{-5}
- ( ) 10^{-4}
- ( ) Other:

Select Scenario

- ( ) Resident
- ( ) Indoor Worker
- ( ) Outdoor Worker
- ( ) Composite Worker (presented in Generic Tables)
- ( ) Construction Worker (Site Specific only)
- ( ) Fish (Site Specific Only)
- (●) Soil to Groundwater
- ( ) Recreator (Site Specific only)

Site-specific
Regional Screening Levels (RSL) for Soil to Groundwater

Key: I = IRIS; P = PPRTV; O = OPP; A = ATSDR; C = Cal EPA; X = PPRTV Screening Level; H = HEAST; D = DWSHA; W = TEF applied; E = RPF applied; G = see user's guide; U = user provided; ca = cancer; nc = noncancer; * = where: nc SL < 100X ca SL; ** = where nc SL < 10X ca SL; SSL values are based on DAF=1; max = ceiling limit exceeded; sat = Csat exceeded.

Chemical	CAS Number	Mutagen?	Volatile?	Chemical Type	SF_o (mg/kg-day)$^{-1}$	SF_o Ref	IUR (ug/m^3)$^{-1}$	IUR Ref	RfD (mg/kg-day)	RfD Ref	RfC (mg/m^3)	RfC Ref	GIABS	ABS	S (mg/L)	K_s (cm^3/g)
Tetrachloroethylene	127-18-4	No	Yes	Organics	2.10E-03	U	2.60E-07	U	6.00E-03	U	4.00E-02	U	1	-	206	1.90E-01

K_{oc} (cm^3/g)	Dilution Attenuation Factor (DAF) (unitless)	HLC (atm-m^3/mole)	Henry's Law Constant (unitless)	H` and HLC Ref	Normal Boiling Point BP (K)	BP Ref	Critical Temperature TC (K)	TC Ref	Noncarcinogenic SL Adult THI=1 (ug/L)	Noncarcinogenic SL Child THI=1 (ug/L)	Carcinogenic SL TR=1E-05 (ug/L)	Water Concentration (Adult) (mg/L)
9.49E+01	20	0.0177	7.24E-01	U	394.15	U	620	U	5.03E+01	4.06E+01	1.13E+02	1.01E+00

Water Concentration (Child) (mg/L)	Water Concentration (Cancer) (mg/L)	Maximum Contaminant Level (MCL) (ug/L)	Water Concentration (MCL) (mg/L)	MCL-based SL (mg/kg)
8.12E-01	2.26E+00	4.10E+01	8.20E-01	3.73E-01

3. Vadose Zone Modelling Approach

GBA Leaching Workshop

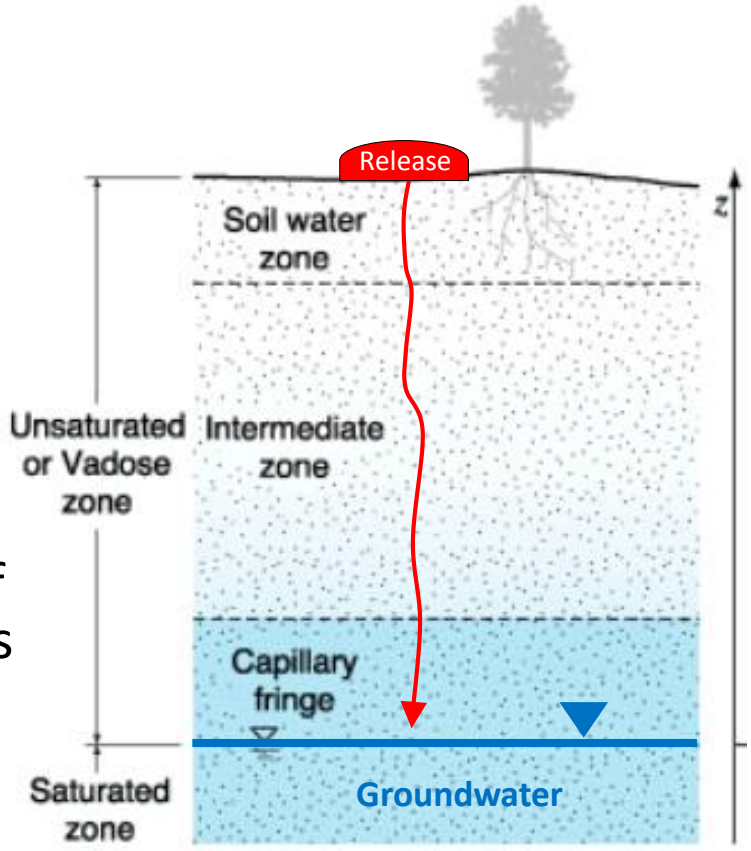
February 28, 2020

Vadose Zone Approach

- Vadose Zone is Unsaturated Subsurface Above the Groundwater
  - Complex Mixture of Air, Water, Organic Carbon, Roots, and Microorganisms Between Soil Particles
- Models Can Estimate Downward Migration of Regulated Substances
  - Detailed Discussion Beyond Scope of This Workshop; But . . .

Common Vadose Models

- Seasonal Soil Compartment Model (SESOIL)
- Vadose Zone Leaching Model (VLEACH)
- Other Popular Models
  - University of California, Divn. of Agriculture & Natural Resources
  - U.S. Geological Survey
  - U.S. Environmental Protection Agency



After: Raffensperger, 1997

4. Leaching Test Approach

GBA Leaching Workshop

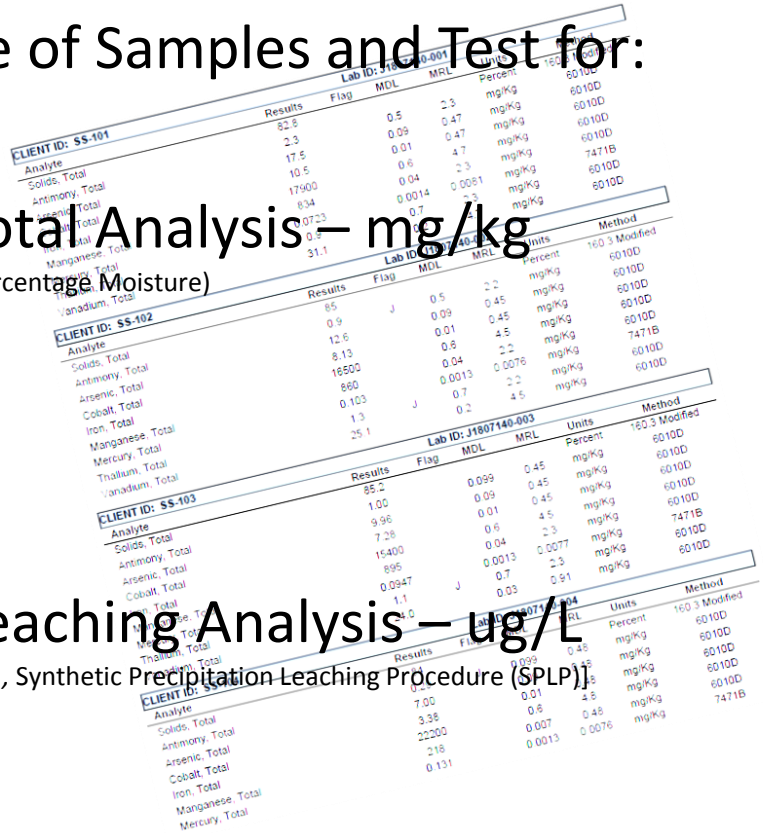
February 28, 2020

Leaching Test Approach

- Run Site-Specific Leaching Tests
- Field Work
  - Collect Sufficient, Representative Samples Over Range of Expected Regulated Substance Concentrations
- Lab Testing
  - Total Concentrations
  - Leaching Tests
- Data Analysis
  - Direct Tabular Comparison
  - Line of Best Fit

Collect Enough Samples

Collect Range of Samples and Test for:



Total Analysis – mg/kg

(Percentage Moisture)

Leaching Analysis – ug/L

[*e.g.*, Synthetic Precipitation Leaching Procedure (SPLP)]

Tabular Comparison Method

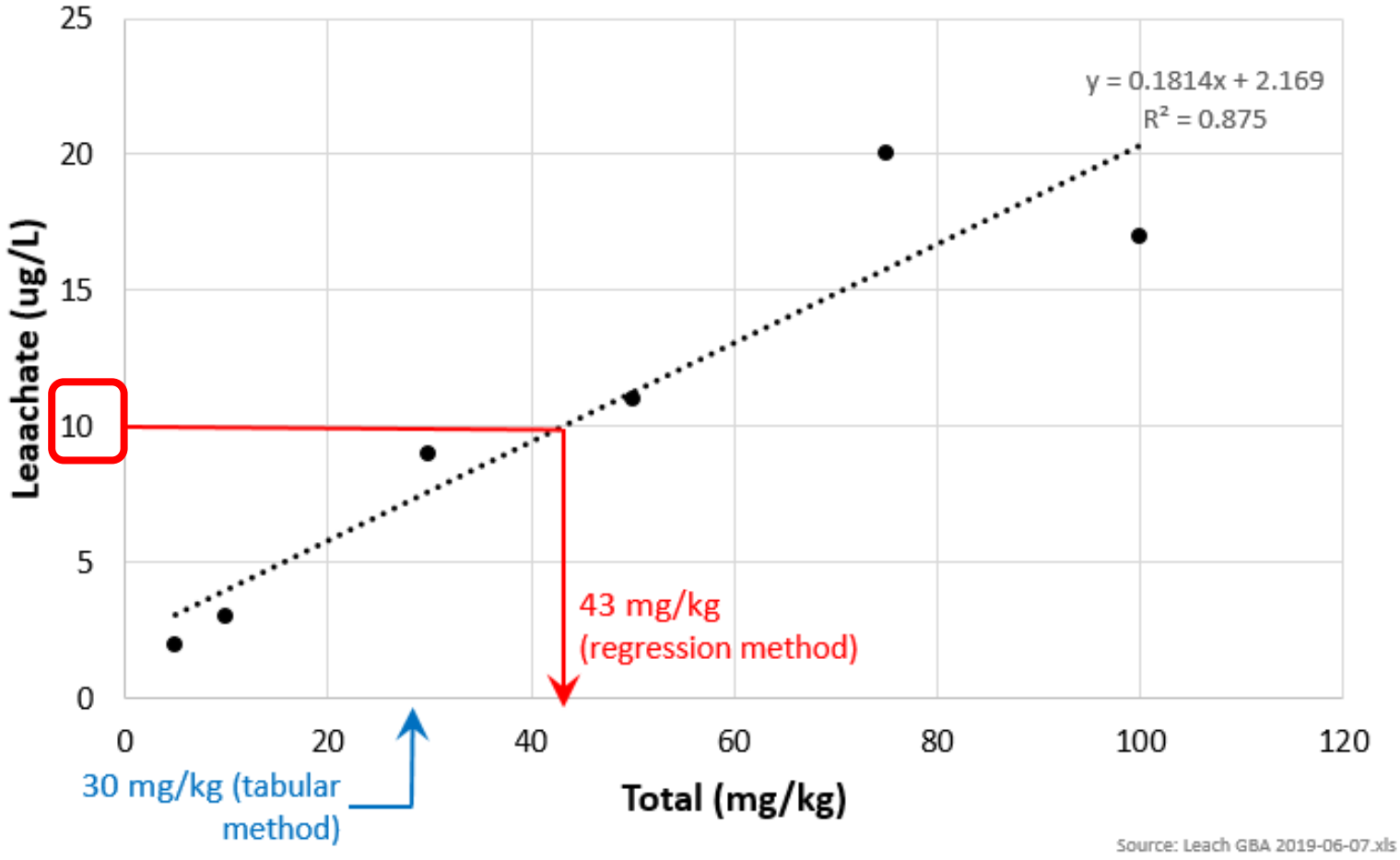
Site-Specific Data for Regulated Substance "X"			
Smpl ID	Total (mg/kg)	Leachate (ug/L)	Criterion (ug/L)
Smpl 001	Low 5	2	10
Smpl 002	10	3	10
Smpl 003	*30*	*9*	*10*
Smpl 004	50	11	10
Smpl 005	75	20	10
Smpl 006	High 100	17	10

Notes/Comments:

Leachate = From USEPA SPLP of other applicable leaching test

Criterion = Risk-based screening value

Line of Best Fit Method
(aka Regression Method)



5. Direct Measurement Approach

GBA Leaching Workshop

February 28, 2020

Direct Groundwater Sampling

- At Least Two Conditions Should be Met:
  - Has Enough Time Elapsed Since Release?
  - Are Measuring Points in Correct Location?

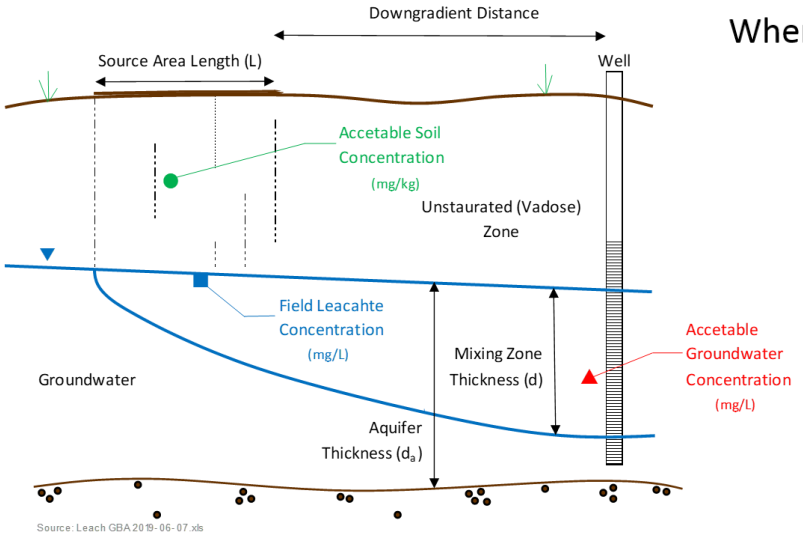
Potential Modifying Factors

- Background Subtraction
- Declining Groundwater Trends
- Risk Assessment
  - Single or Combination of Regulated Substances
  - Mutagenic Carcinogens
  - Critical (Target Organ) Effect for Non-Carcinogens
- Mass-Limit Considerations
- Downgradient Attenuation In Groundwater
  - Regulatory Compliance Point or Actual Exposure
    - Dilution Attenuation Factor (DAF)
    - Groundwater Fate and Transport Models

Site-Specific DAF

$$DAF = 1 + \frac{Kid}{LI}$$

$$d = (0.0112 * L^2)^{0.5} + d_a\left[1 - exp\left(\frac{-LI}{Kid_a}\right)\right]$$



Where:

DAF = Dilution Attenuation Factor (unitless)

K = Hydraulic conductivity (ft/yr)

i = Hydraulic gradient (ft/ft)

d = Mixing zone thickness, cannot exceed d_a (ft)

L = Source length parallel to groundwater flow (ft)

I = Infiltration rate (ft/yr)

d_a = Aquifer thickness (ft)

Source: USEPA, 11996; Eq. No. 11 & 12, page 31

Thank You

Stephen B. Ellingson, Ph.D.
Principal
Vatten Associates
3600 Dallas Hwy, Suite 230-375
Marietta, GA 30064
steve.ellingson@vattenassociates.com
P 678.512.9688 F 678.331.3881