ES/RP 531
Fundamentals of Environmental Toxicology

Lecture 19

Mass Transfer (Transport)

Transport Phenomena

- Diffusion
- Volatilization
- Runoff & Erosion
- Leaching

(Mass Transfer)

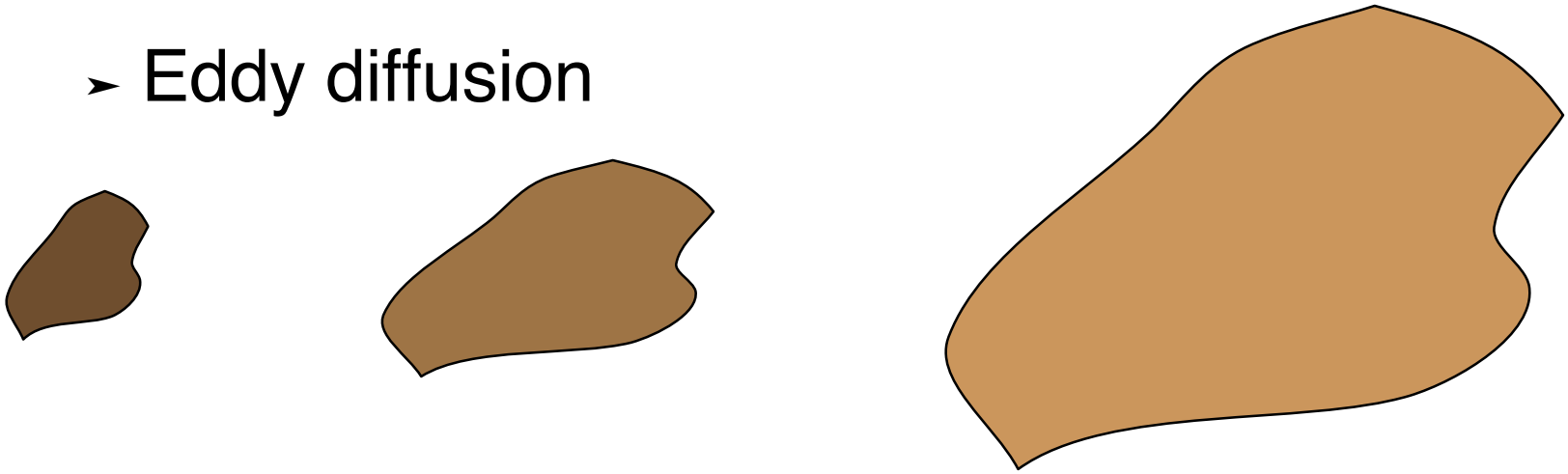
Diffusion

- Molecular scale process
  - Movement of molecules within a medium
  - Movement from higher concentrations to lower concentrations
  - Loss of spatial uneveness in the distribution of mass (concentration, or heat) manifested because of the second law of thermodynamics
    - Entropy increases until equilibrium is reached
    - System at lowest energy state at equilibrium

Diffusivity is related to molecular size of the contaminant and viscosity of the medium

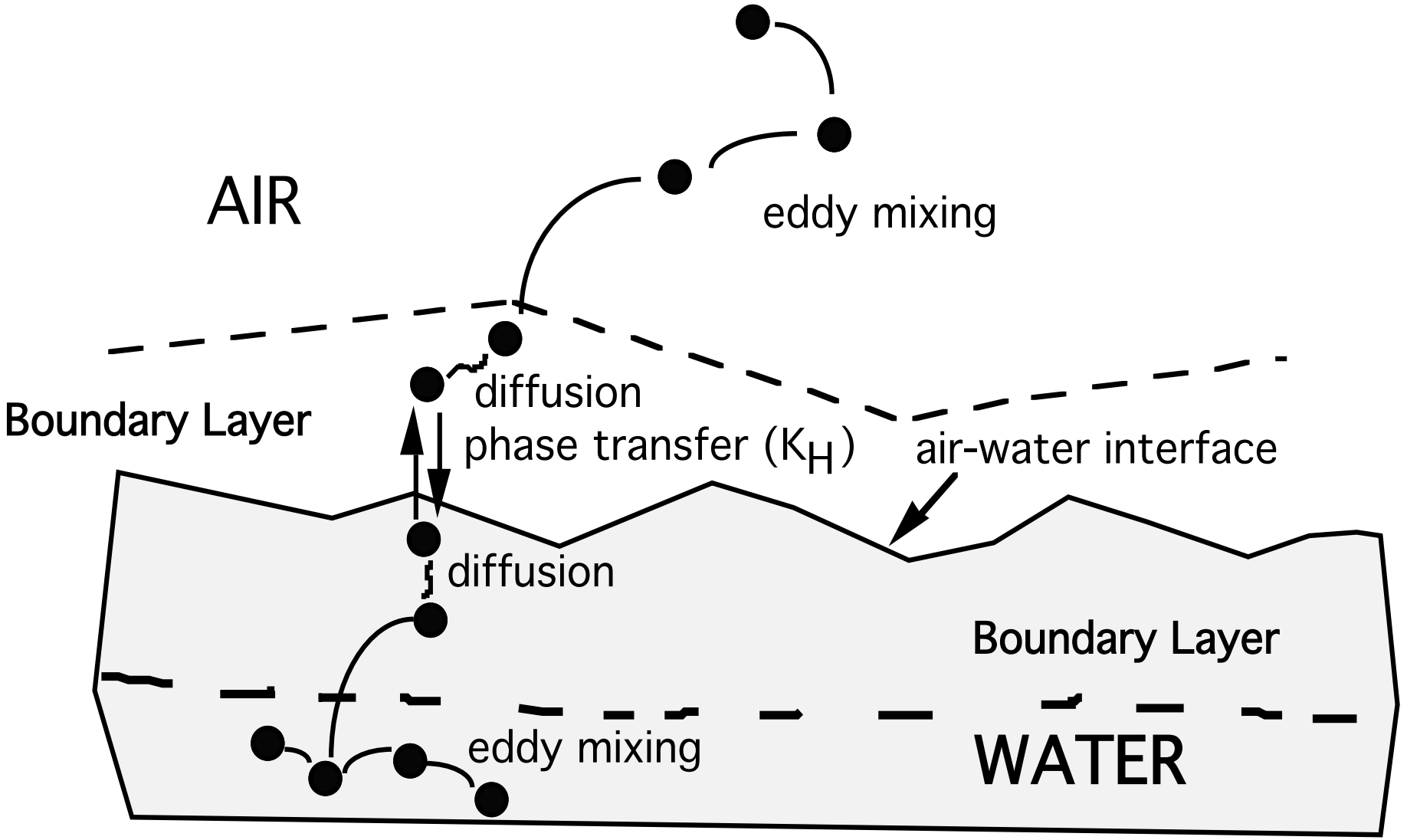
Turbulent Diffusion

- Macroscopic level “diffusion”
  - Movement of medium itself redistributes the contaminant
  - Eddy diffusion

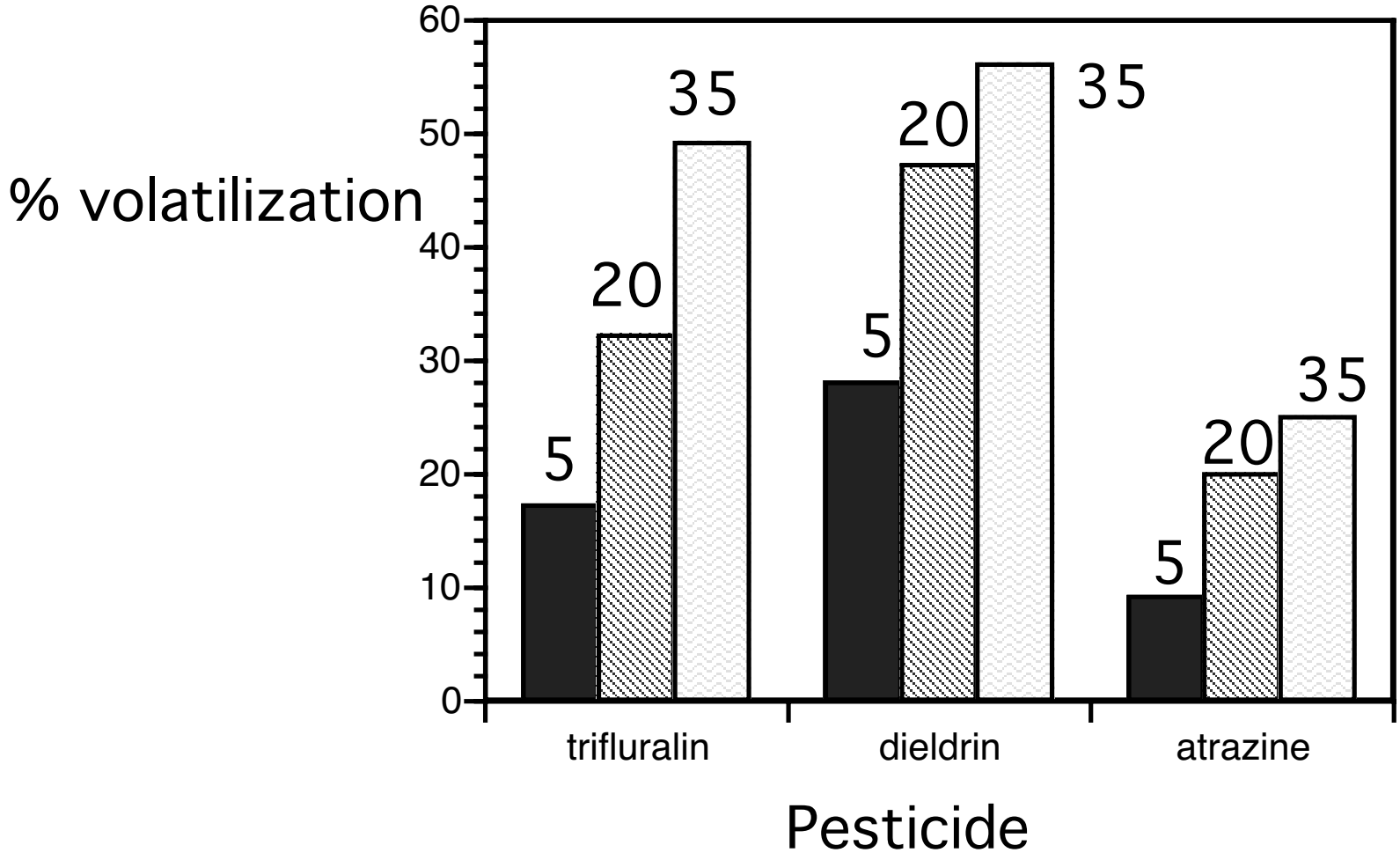


Diffusion occurs quickly over short distances (100 μm) but very slowly over long distances.

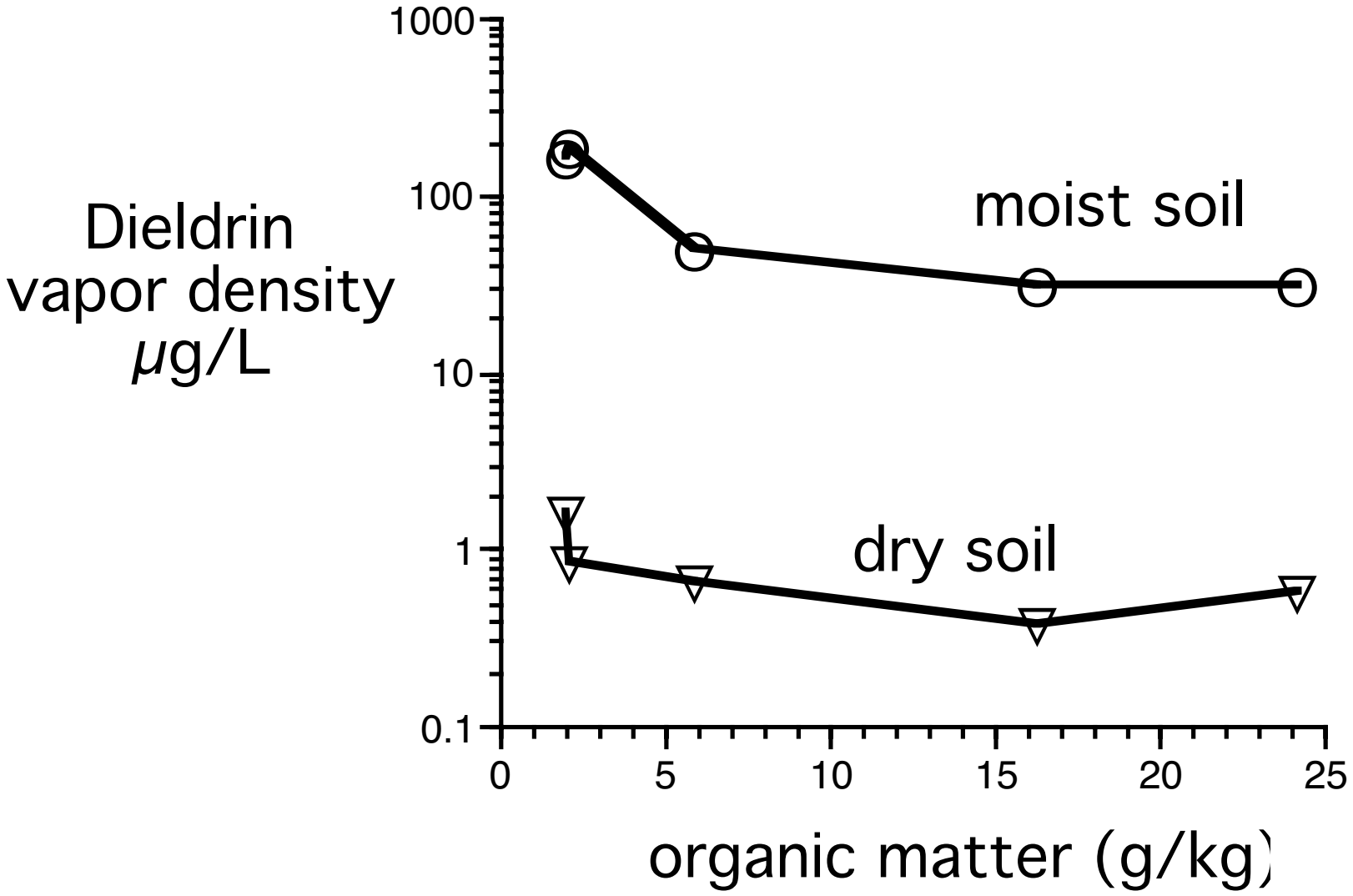
Volatilization



Volatilization is influenced by temperature.



Volatilization is influenced by soil moisture and organic carbon.



Effect of Perturbations on Volatilization of PCBs

System	sediment (ng/g) 0-5 mm depth	water (ng/L)	surface microlayer ng/cm^2	jetdrop impactor ng/cm^2
w/ midges	123	0	92	16
w/ worm & midges	37	6	76	8
sterile	56	0	0	0
no animals	145	0	0	0

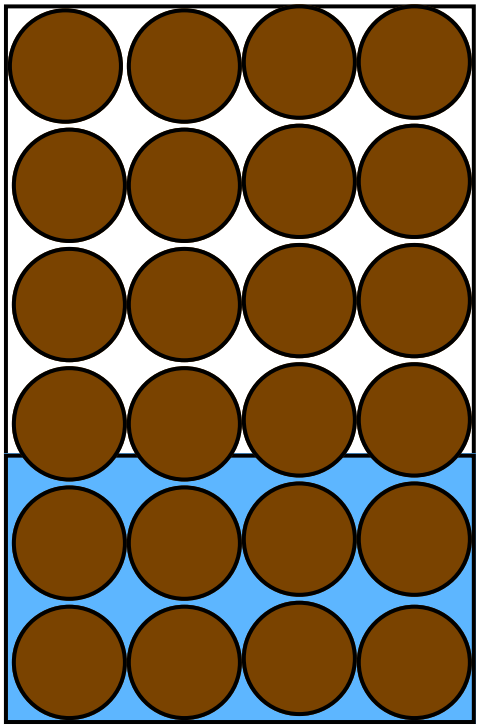
Volatilization

Pesticide	% Volatilized in 24 hours	Crop
alachlor (Lasso)	1.1	fallow
atrazine (Aatrex)	0.1	fallow
simazine (Princep)	0.05	fallow
EPTC (Eradicane)	33.6	alfalfa
2,4-D	4.2	wheat
trifluralin (Treflan)	41.4	fallow (moist)
trifluralin (Treflan)	11.9	fallow (dry)

Spencer 1990

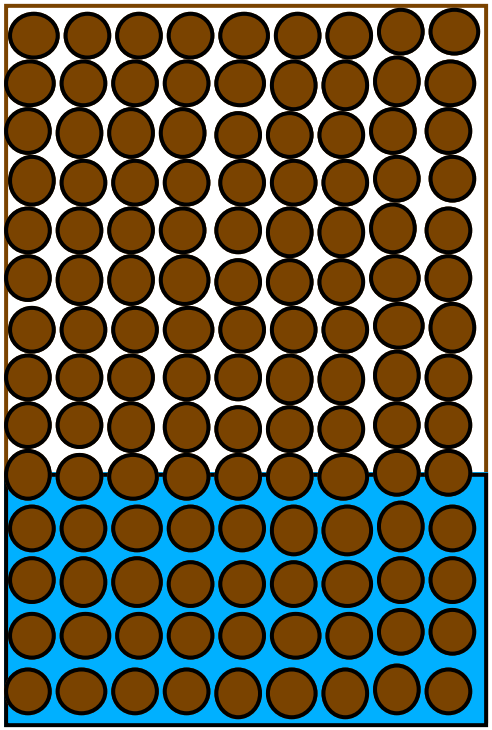
Soil Models for Texture & Moisture Holding Capacity

Coarse



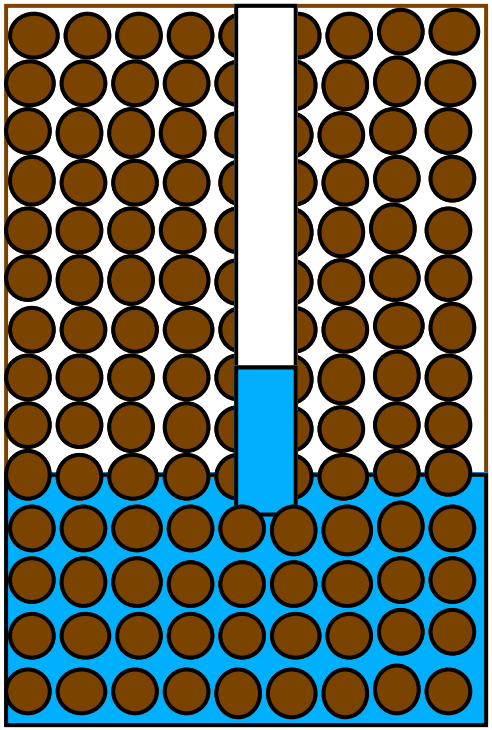
Sand
(large particles)

Fine



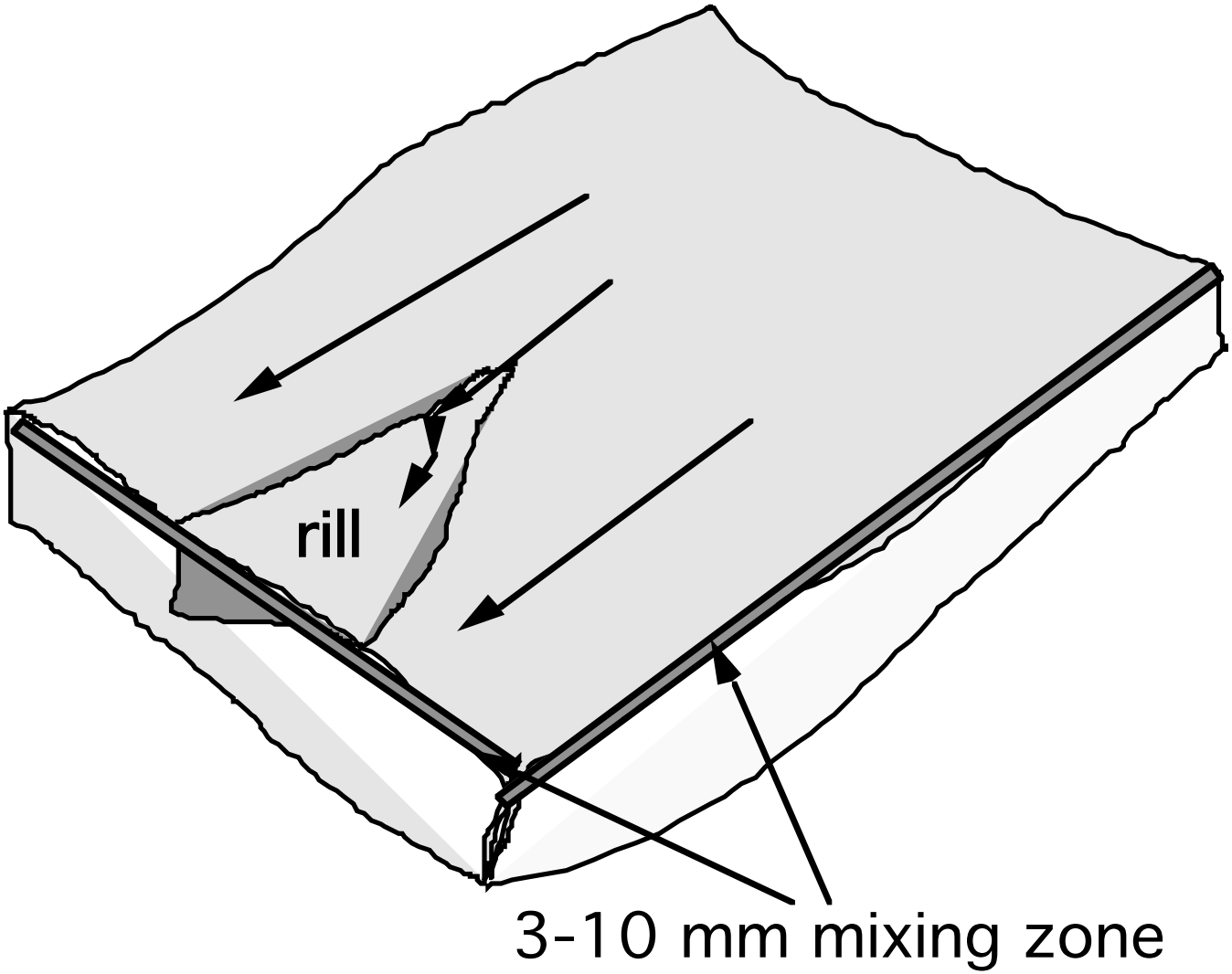
Silt Loam
(small particles)

Fine



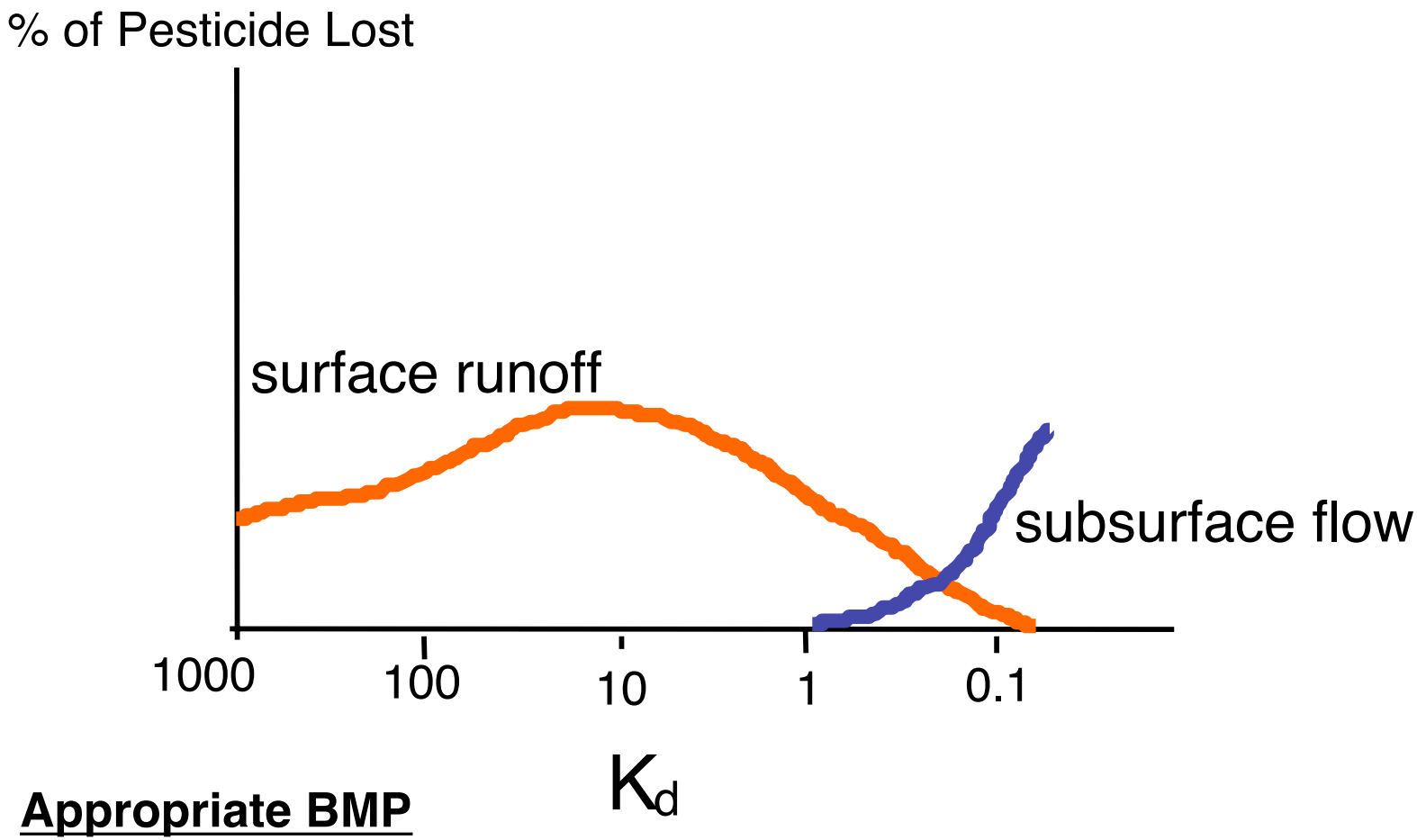
Silt Loam
(with macropore)

Runoff & Erosion



Factors Affecting Surface Transport

- Rainfall timing & intensity
- Location of contaminant
- Contaminant properties
- Topography



Appropriate BMP

erosion & sediment control

runoff control & chemical incorporation

timing, rate formulation additives

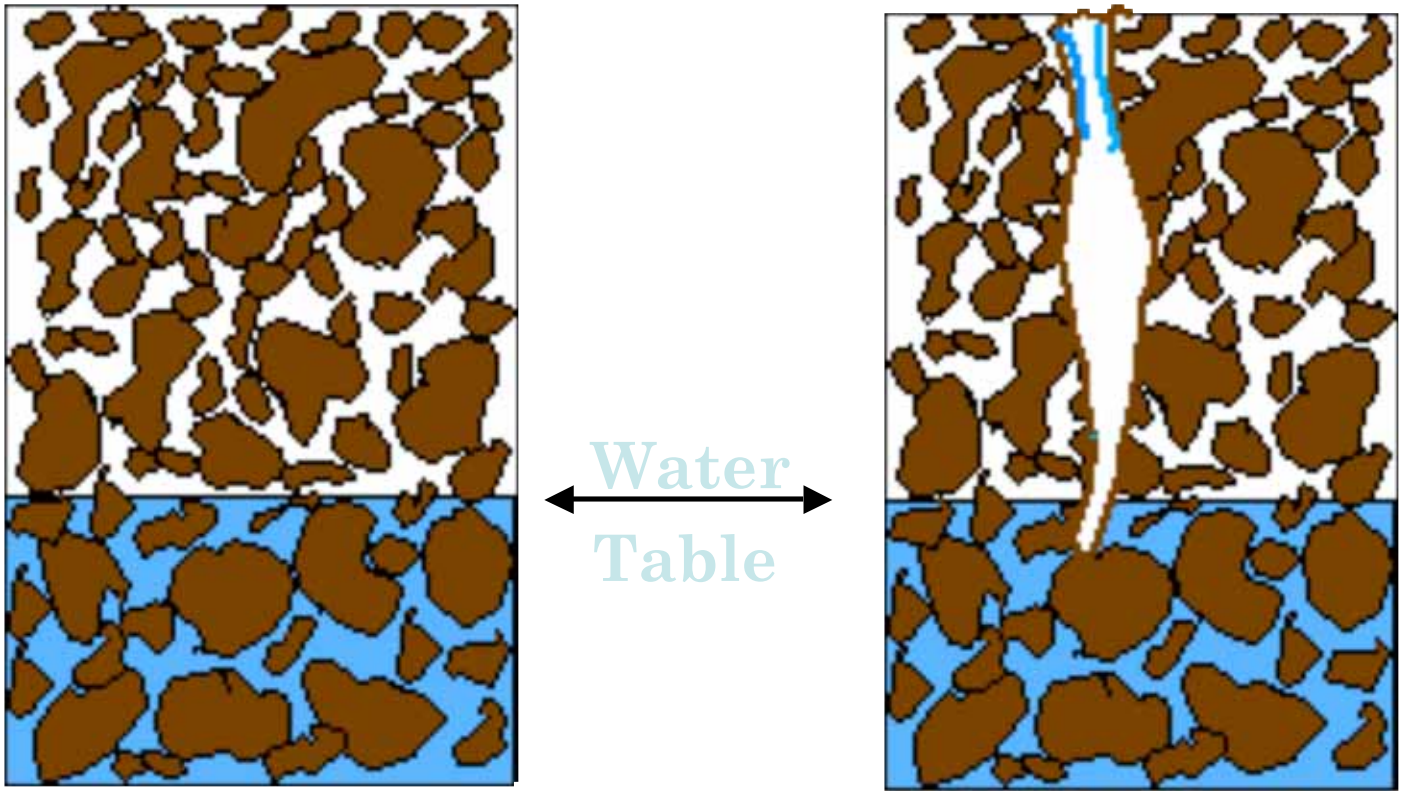
Contaminant Properties Affecting Leaching

- Water solubility
- Sorption potential
- Volatilization potential
- Reactivity

Field Factors Affecting Leaching

- Precipitation & Irrigation
  - Volume
  - Intensity
- Soil Properties & Structure
  - Organic matter content
  - Clay content
  - pH
  - Macropores

Reality is Irregular



Soil particles are irregular, creating small and lare pores.

Old root channels or earhworm burrows create macropores.

Macropores

- Large continuous openings in field soils
- May be continuous for distances of several meters in both vertical and lateral directions
- Characteristic of structured soils
- Cause preferential flow
  - aka macropore flow
  - flow velocities ~0.3 mm/sec -- 20 mm/sec

Macropores

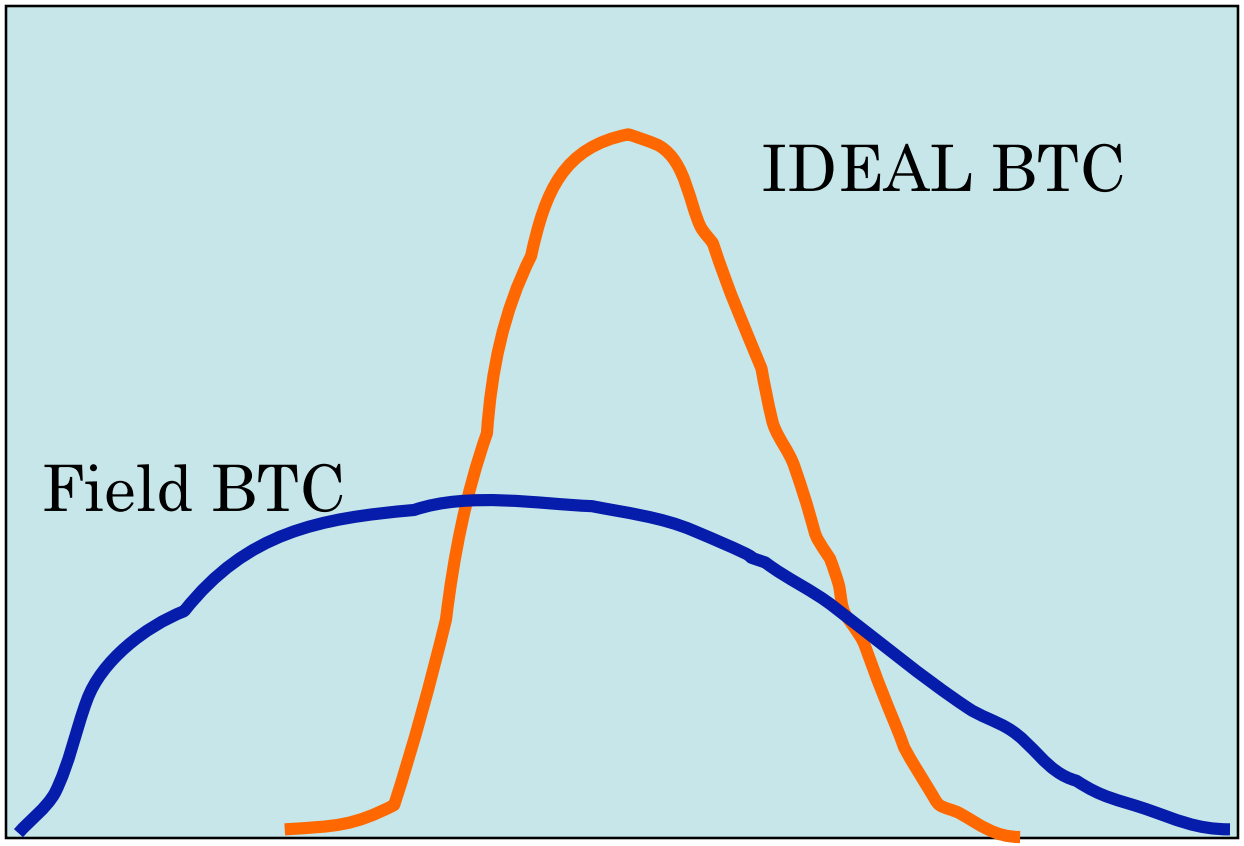
- Pores formed by soil fauna
  - ~1 mm - >50 mm
- Pores formed by plant roots
  - < 1 mm
- Pores formed by cracks & fissures
  - variable sizes

Preferential Flow

- Rapid movement of water along facilitated pathways resulting in water movement through only a fraction of the available pore space
  - macropores
  - heterogenous pore sizes

Breakthrough Curves

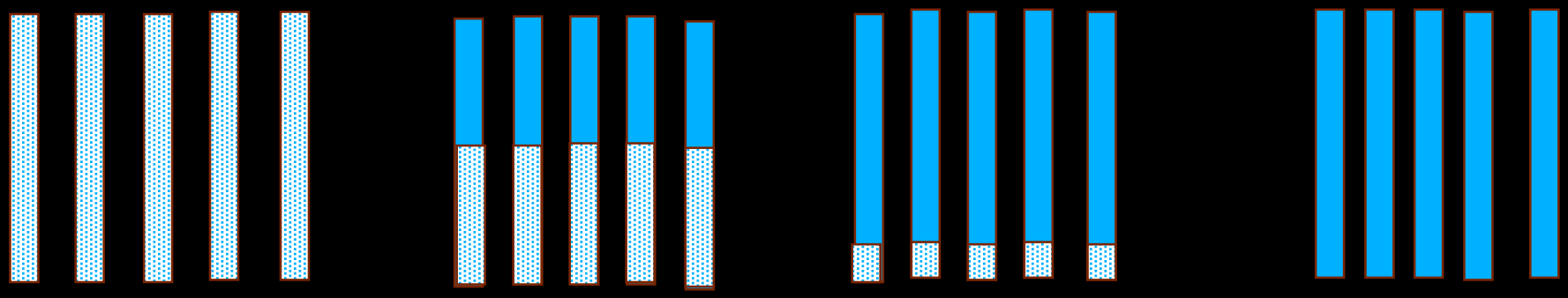
[C]

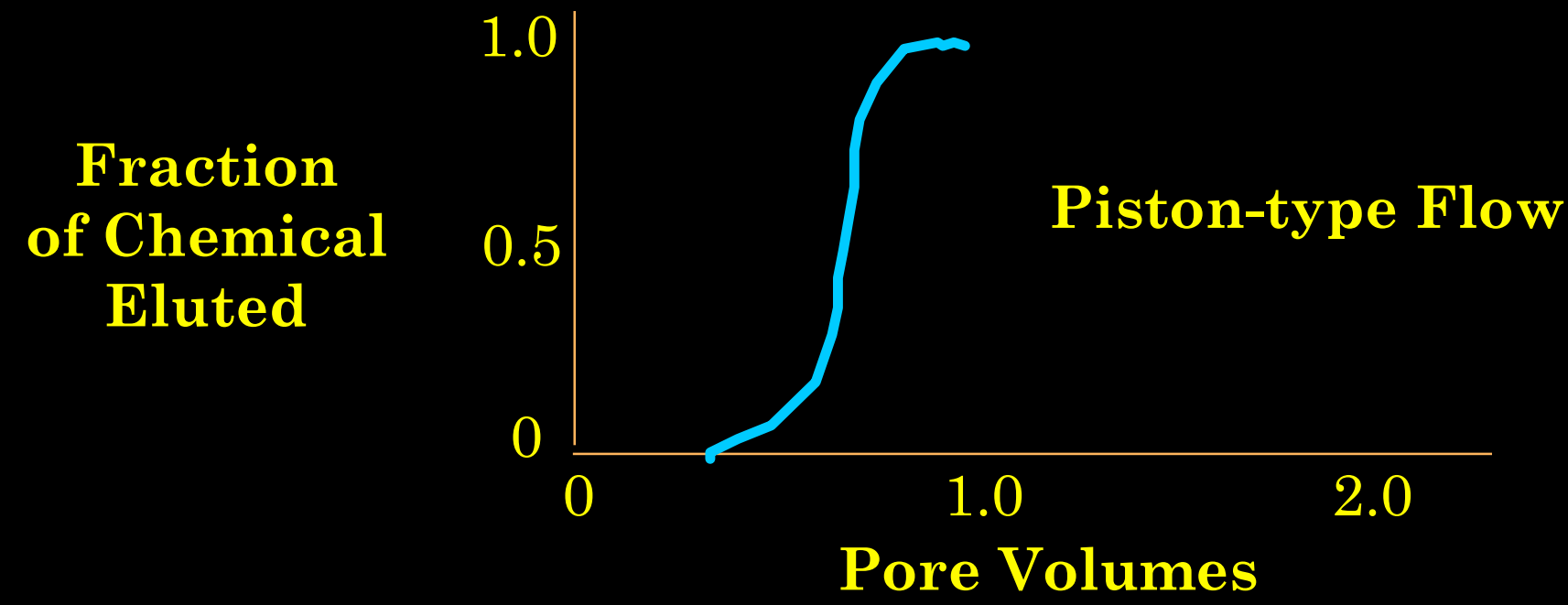


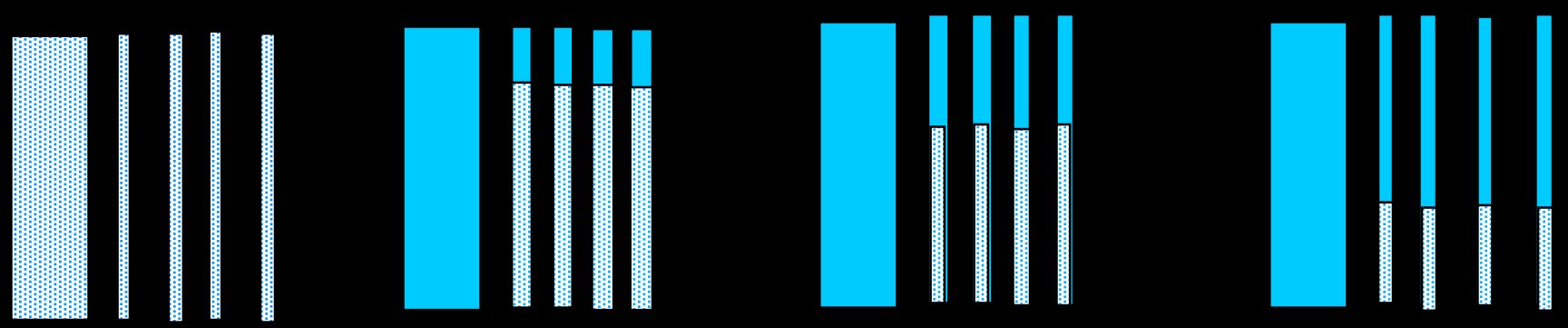
Volume of Water Leached

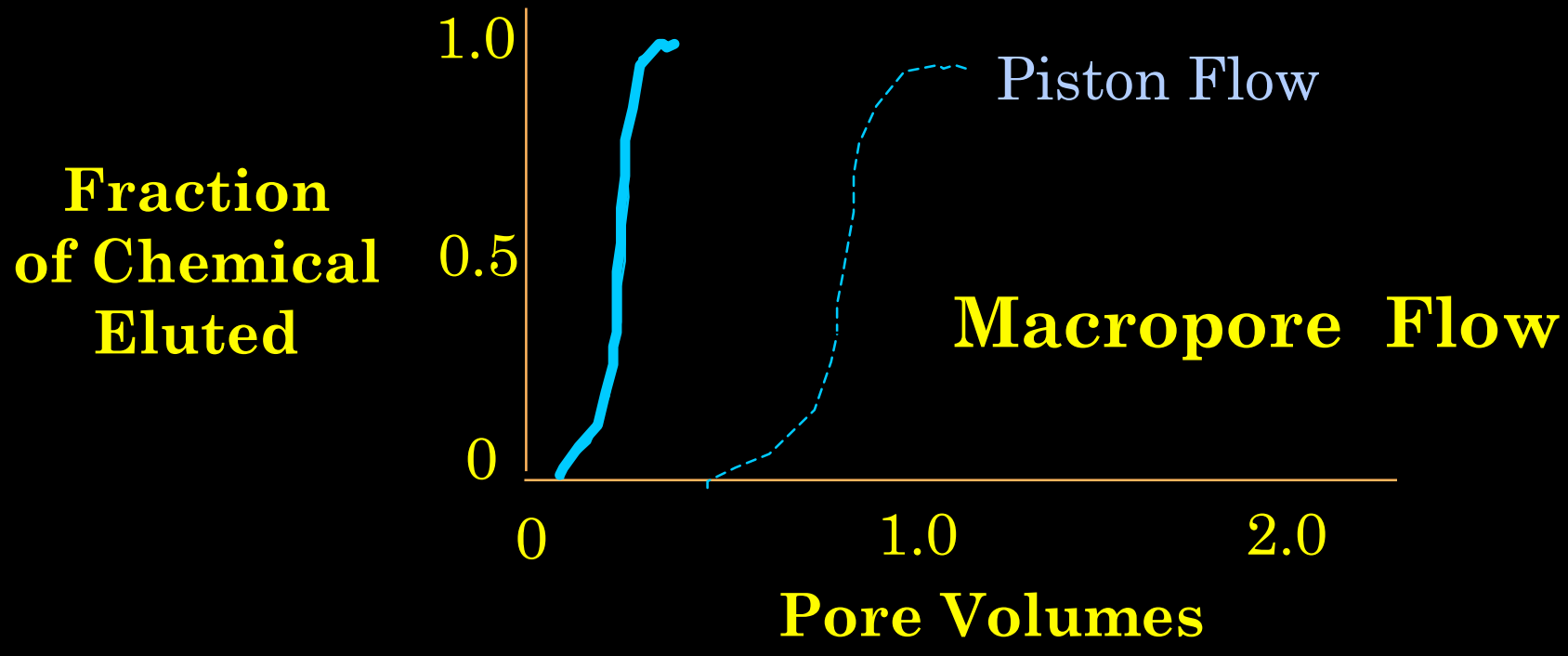
Importance of Preciptiation Rate & Infiltration Rate

- When precipitation rate is slow relative to infiltration rate, flow occurs through micropores
- When precipitation rate is close to infiltration rate, macropore flow occurs
- When precipitation rate exceeds infiltration rate, surface runoff occurs




Fraction of Chemical Eluted
1.0
0.5
0
0
1.0
2.0
Pore Volumes
Piston-type Flow




1.0
0.5
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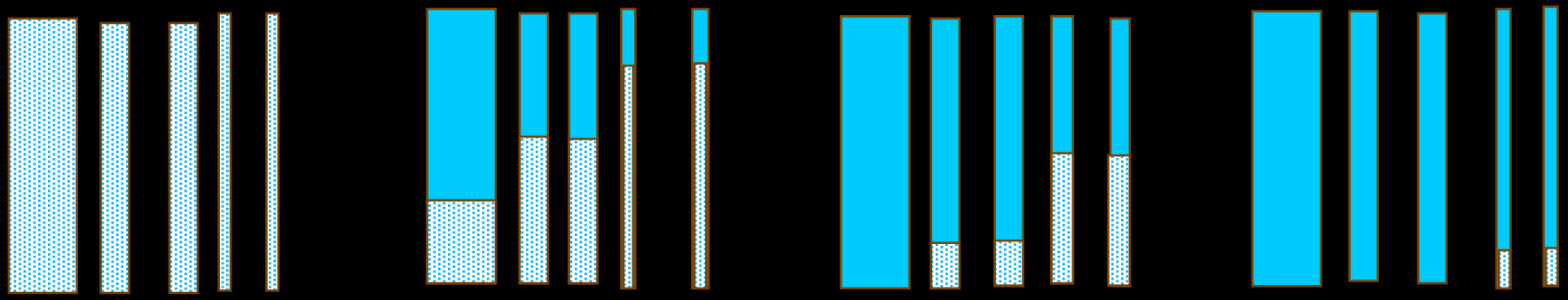
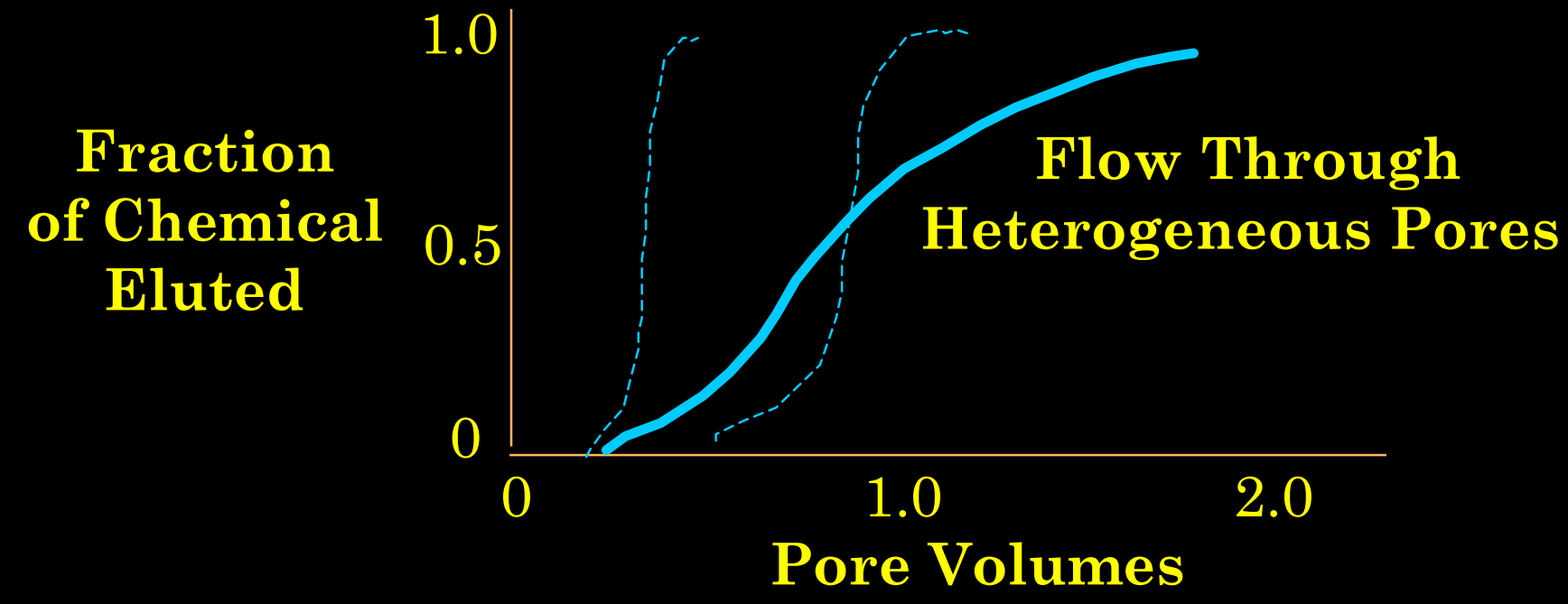
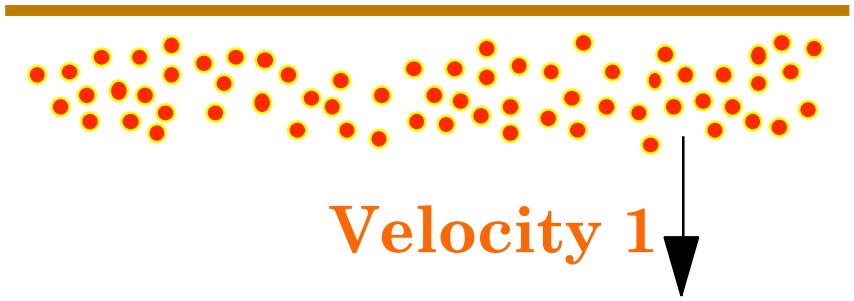
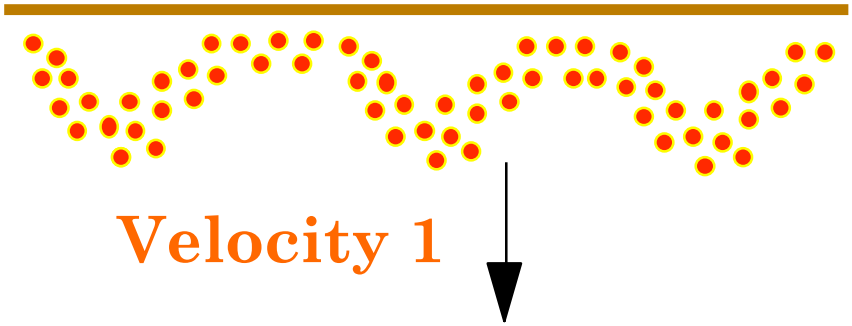
Fraction of Chemical Eluted
Piston Flow
Macropore Flow
0
1.0
2.0
Pore Volumes



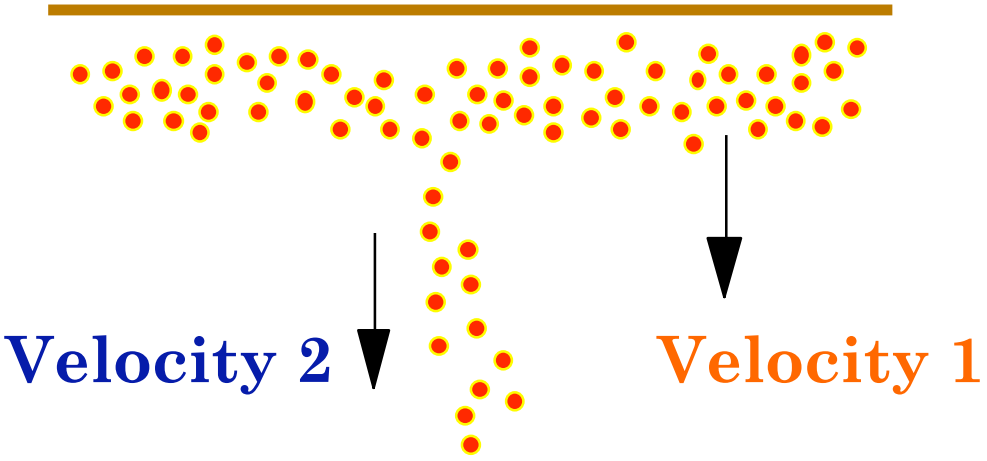

Fraction of Chemical Eluted
1.0
0.5
0
0
1.0
2.0
Pore Volumes
Flow Through Heterogeneous Pores



Uniform Pores
Piston Flow
Mixing > Convection

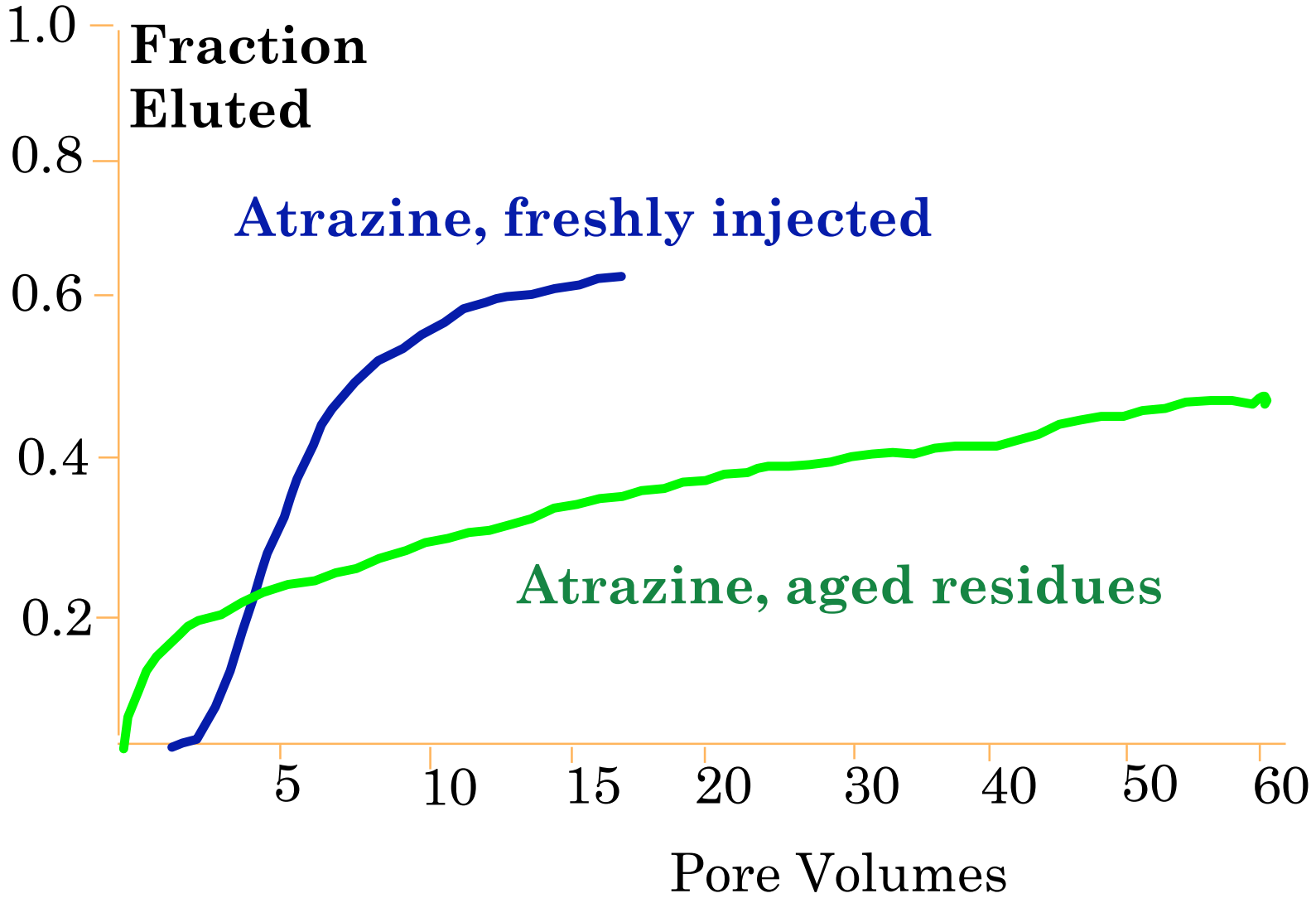


Heterogenous Pores
Convection > Mixing



Macropore Flow
(Preferential Flow)
Mixing > Convection
Convection > Mixing

Aging of Residues Slows Leaching



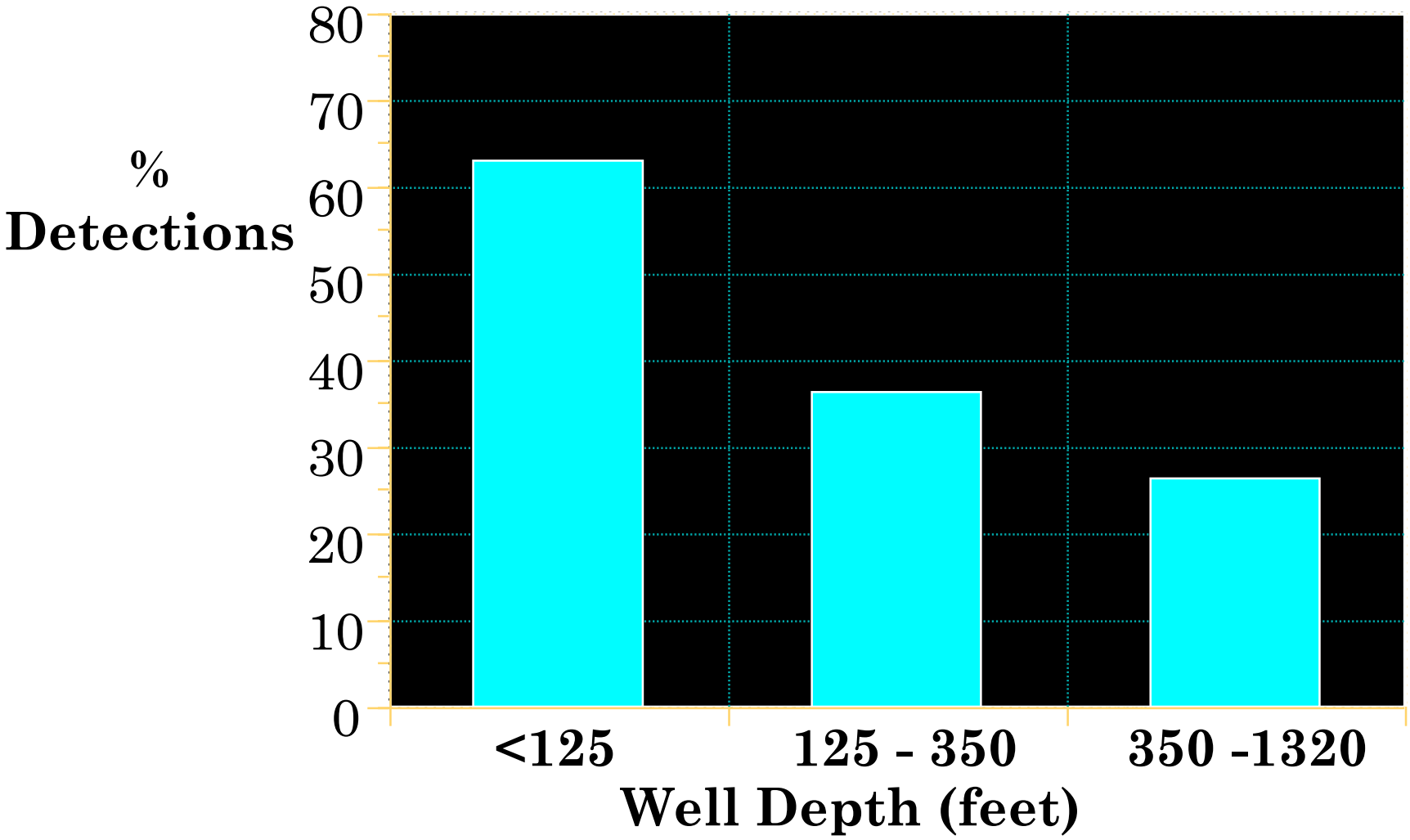
Pignatello et al. 1993

Operational Factors Affecting Leaching

- Depth of Well
- Well Maintenance
- Timing of Application
- Waste Disposal Practices
- Irrigation System

Deeper Wells--Less Detections

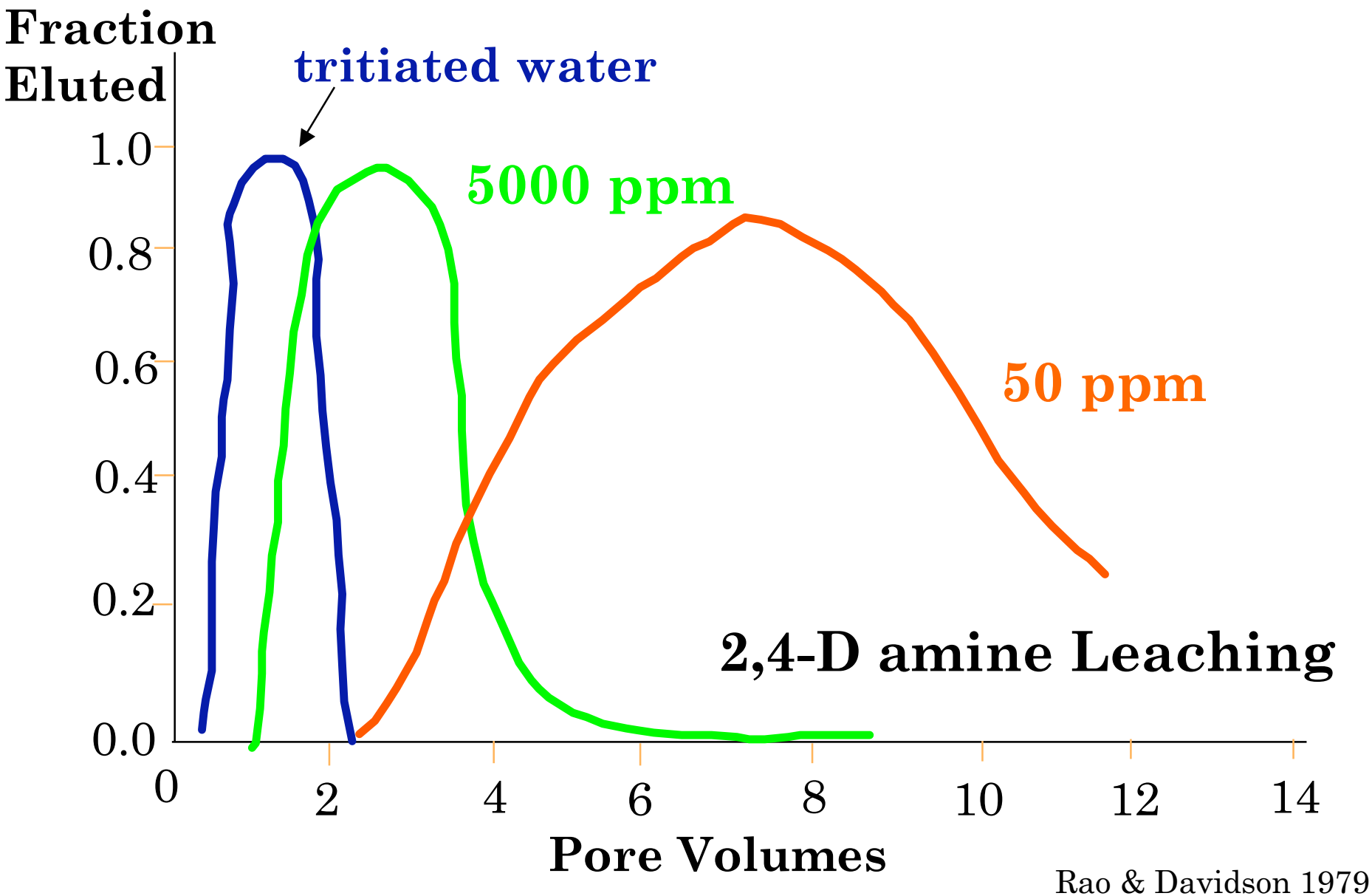
USGS Analysis of Public Water Supply Wells
(Central Columbia Plateau -- **1994**)



Waste Disposal & GW Contamination

- Many agrichemical facilities with contaminated soil & wells
- High concentrations favor
  - persistence
  - leaching

Velocity of Leaching Is Affected by Concentration of Chemical

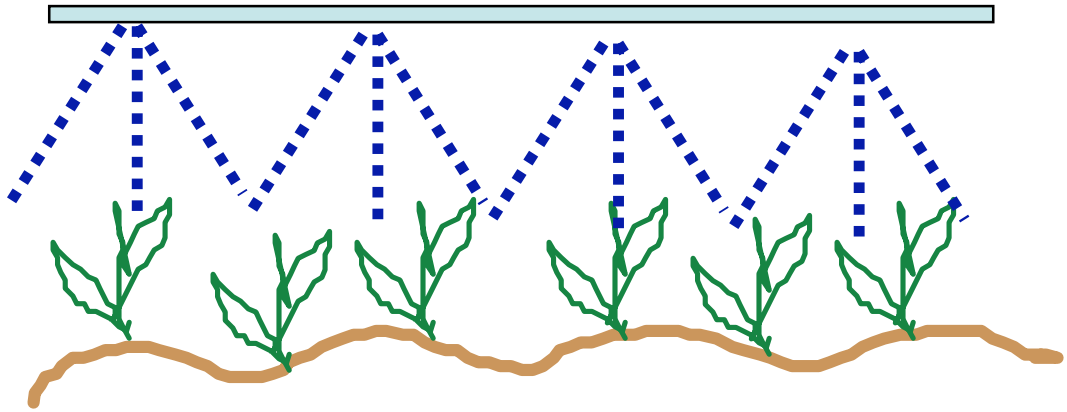


Rao & Davidson 1979

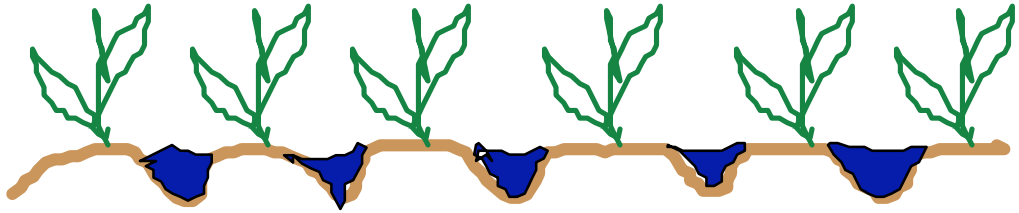
Recharge

- Irrigation in the Columbia Basin has raised the water table and the yearly recharge rate
  - Whitman Co.
    - 2 - 5 inches per yr
  - Franklin Co.
    - >10 inches per yr

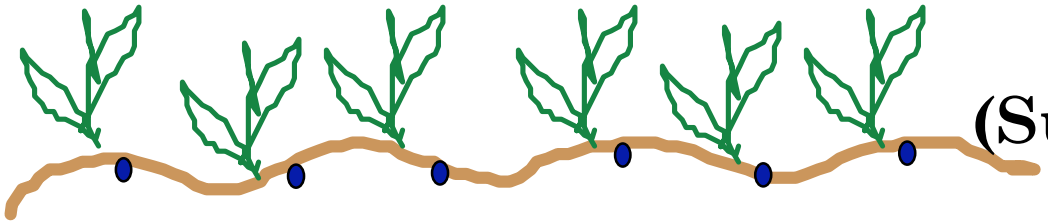
Irrigation Style Affects Leaching



Overhead Sprinkler

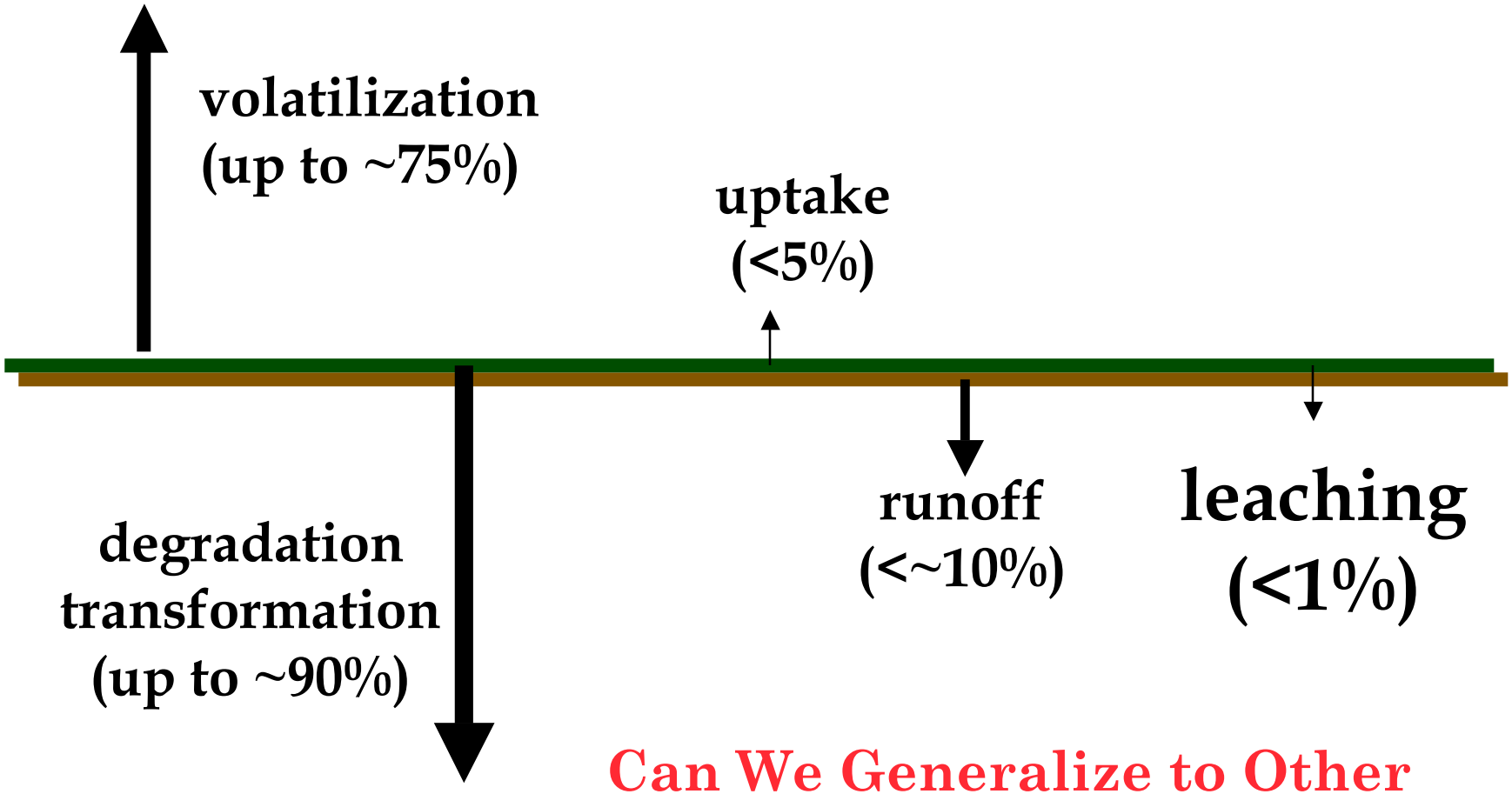


Furrow



Microirrigation (Surface or Subsurface)

Proportional Disappearance of Pesticides from Soil by Different Pathways



Can We Generalize to Other Contaminants????