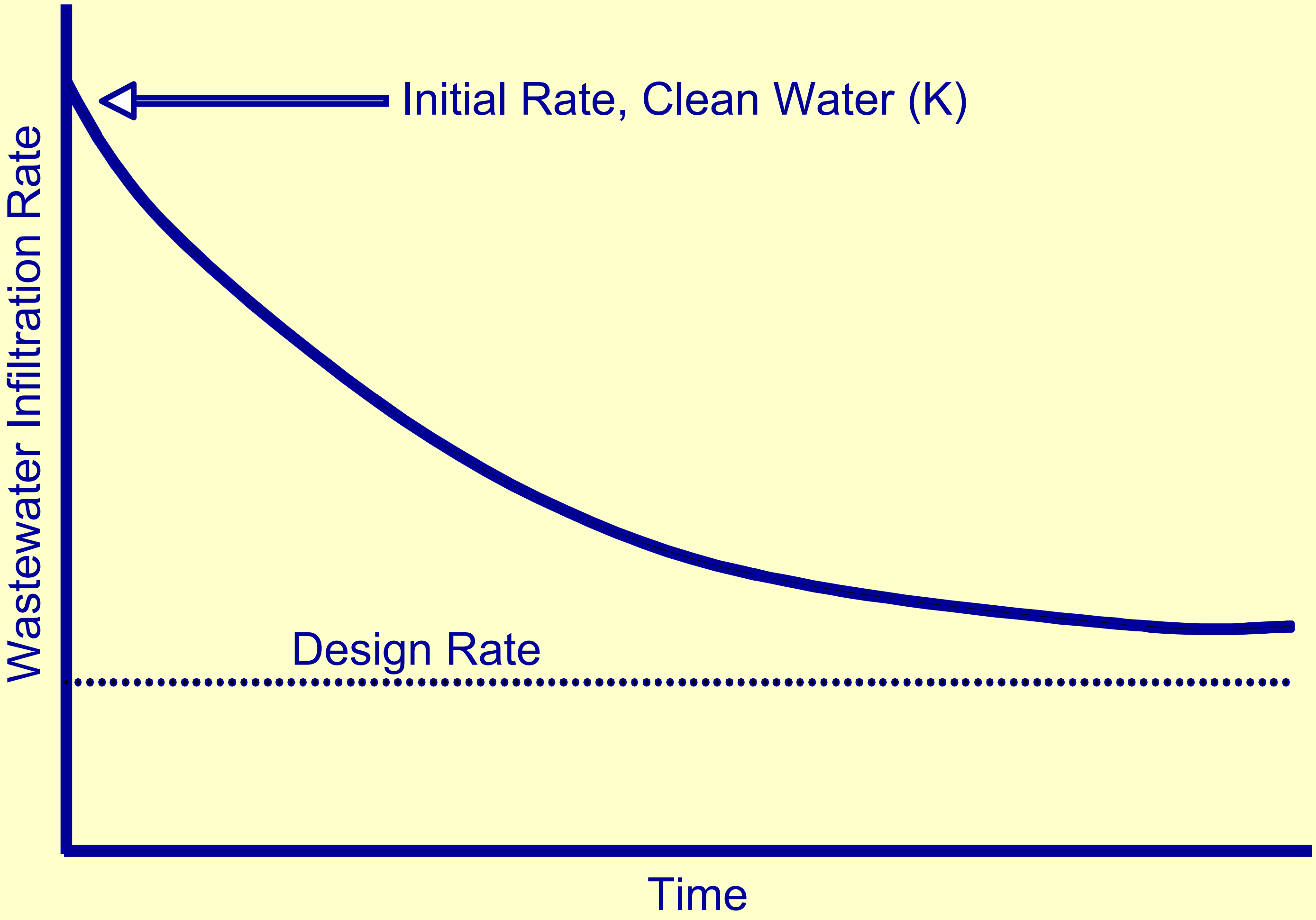
Hydraulic Properties of Drainfield Trench Biomats Formed in Georgia Soils

S.D. Finch, L.T. West, D.E. Radcliffe, and E.V. Hufstetler
Department of Crop and Soil Sciences
University of Georgia

Onsite System Drainfield Sizing

- Sizing based on relationships developed from experience
  - Y ft^2/bedroom for a given perc rate (estimated or measured with clean water)
  - Long-term acceptance rate (LTAR; gpd/ft^2) based on soil and landscape properties
- Accounts for wastewater infiltration rate decline from watewater loading
- Normally contains a hidden safety factor

Wastewater Infiltration Rate Over Time



Wastewater Infiltration Rate Decline

- Soil changes in response to wastewater loading
  - Structure degradation under consistently wet conditions
  - Clay dispersion from Na in wastewater
- Pore clogging by organic material
  - Biomat formation

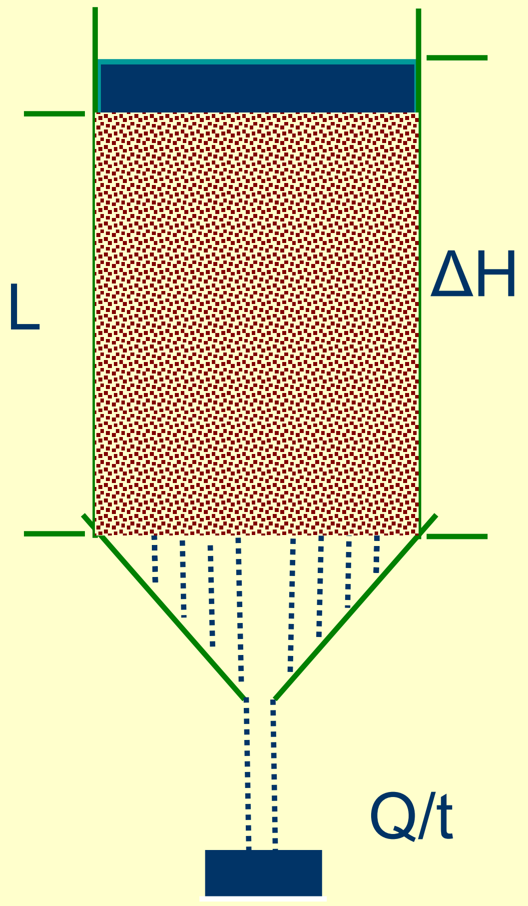
Can we be more quantitative?

- Measure or estimate soil hydraulic conductivity (K)
  - Saturated or unsaturated
- Account for change in infiltration rate from wastewater loading
- Add safety factor if desired

  LTAR = (K) X (infiltration rate reduction) X (safety factor)
- Simple concept, but limited information on impact of wastewater loading on changes in wastewater infiltration rate

Theory

Darcy's Law

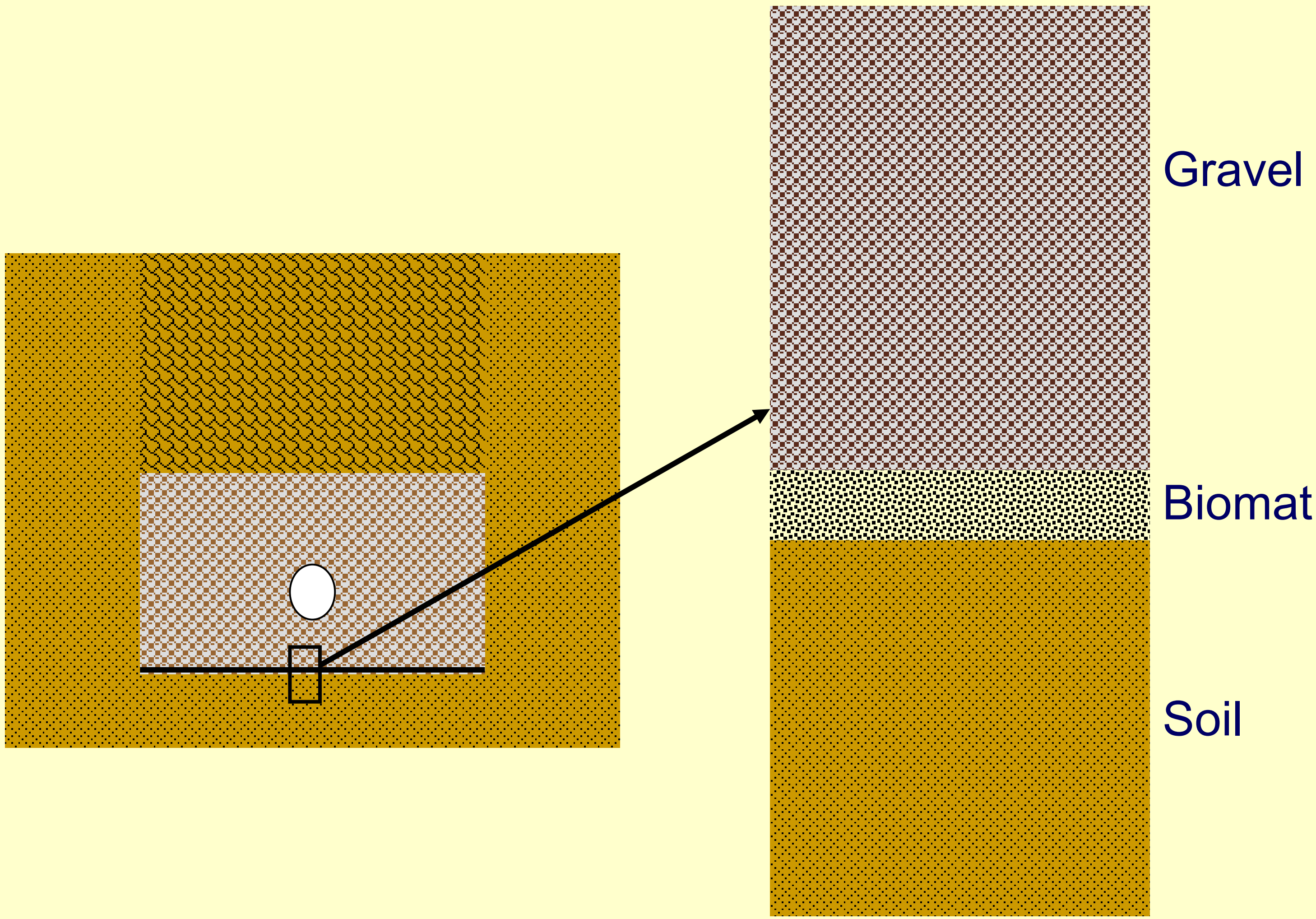


$Q = KA(\Delta H/L)$

$J\ (cm/h) = Q/A = K(\Delta H/L)$

- Parameters that affect flow rate
  - Head (pressure)
    - Pressure on water faucet
  - Length of flow path
    - Hose length
  - Hydraulic conductivity
    - Size of hose and how crooked it is

Trench-Soil Interface



Hydraulic Resistance (R)

- Resistance to water moving through material
- Rearrange Darcy's Law

$$J = K_s(\Delta H/L)$$

$$R = L/K_s = \Delta H/J$$

- Length of flow (L) relative to hydraulic conductivity

$$R = L/K_s$$

or

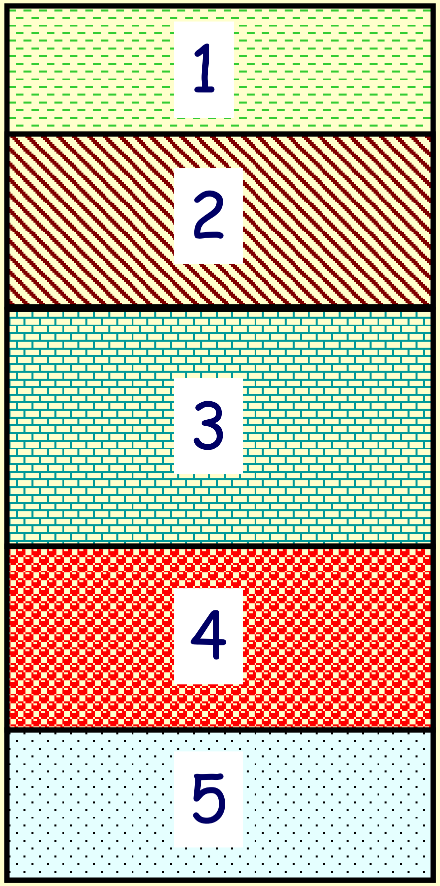
- Amount of head (ΔH) relative to flow rate (J)

$$R = \Delta H/J$$

For a number of layers, effective resistance is sum of resistance of each layer (similar to electrical resistance)

$$R_{eff} = R_1 + R_2 + R_3 + R_4 \ldots + R_n$$

Effective Hydraulic Conductivity (K_{eff})



$R_{eff} = R_1 + R_2 + R_3 + R_4 + R_5$

$R_{eff} = L_1/K_1 + L_2/K_2 + L_3/K_3 + L_4/K_4 + L_5/K_5$

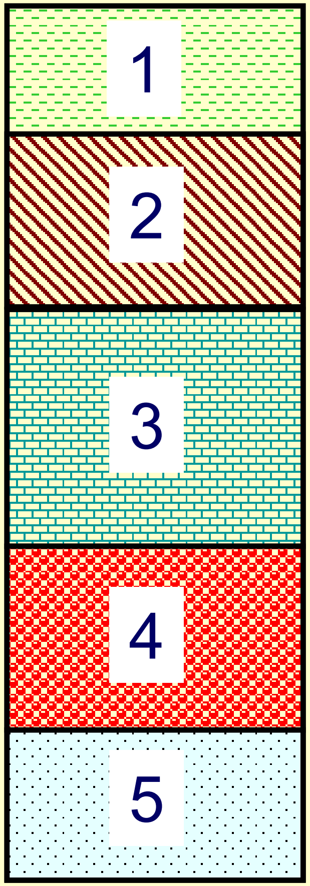
$L_{total} = L_1 + L_2 + L_3 + L_4 + L_5$

$K_{eff} = L_{total} / R_{eff}$

$K_{eff} = L_{total} / (L_1/K_1 + L_2/K_2 + L_3/K_3 + L_4/K_4 + L_5/K_5)$

An Example

cm/d cm



K = 1; L = 5

K = 2; L = 8

K = 3; L = 10

K = 4; L = 9

K = 5; L = 6

$R = L/K$

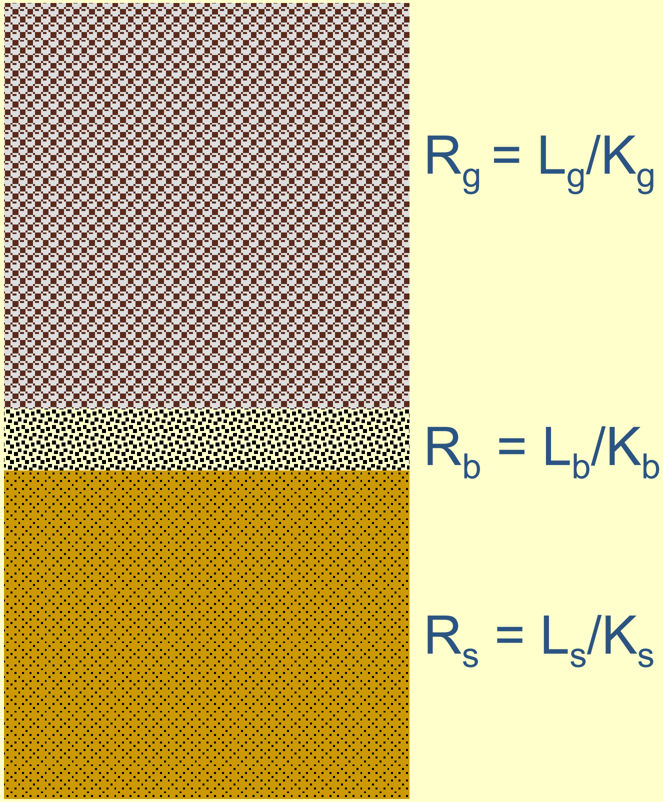
$K = L/R$

$R_{eff} = 5/1 + 8/2 + 10/3 + 9/4 + 6/5 = 15.78\ d$

$L_{sum} = 5 + 8 + 10 + 9 + 6 = 38\ cm$

$K_{eff} = 38/15.78 = 2.4\ cm/d$

How Does this Relate to LTAR?



K_{eff} = Total Length/R_{eff}

$R_{eff} = L_g/K_g + L_b/K_b + L_s/K_s$

L_g – known

K_g – large

L_g/K_g – small number ~ 0

L_s – unknown but can be estimated

K_s – can be measured

L_b – unknown

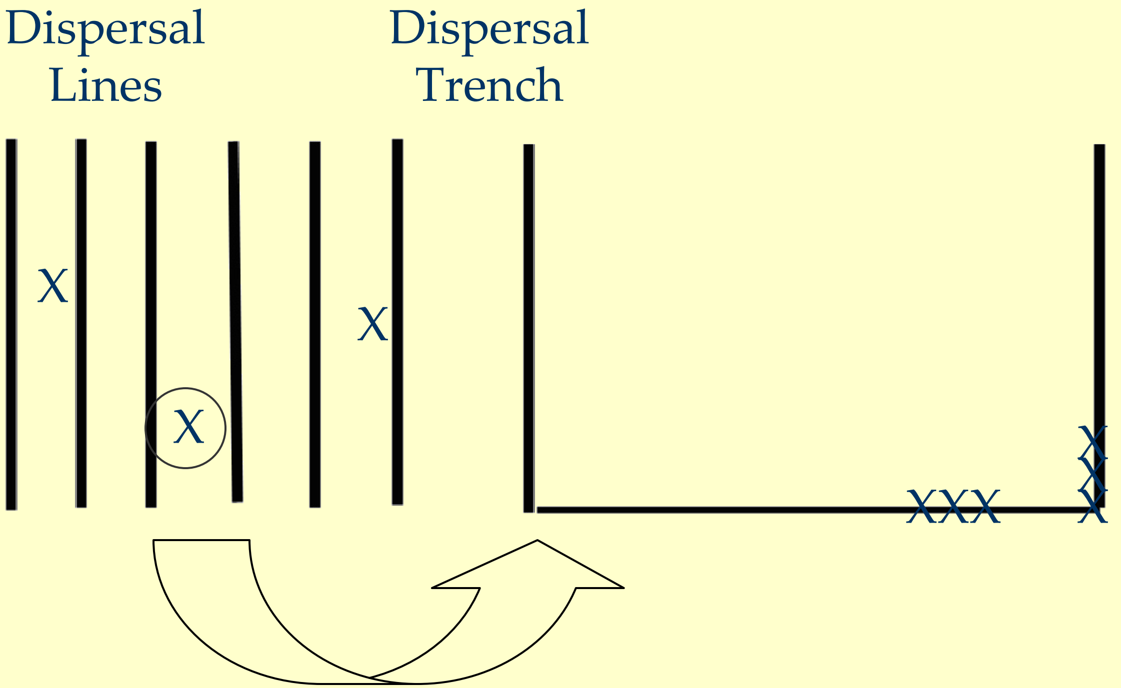
K_b - unknown

Objectives

- Measure K_{eff} for soil-biomat drainfield systems
- Measure biomat thickness
- Estimate biomat saturated hydraulic conductivity (K_s)

Field Methods

- 7 sites in Piedmont and Coastal Plain of Georgia
- Samples collected from mature drainfields
  - 5 to 40 years old
  - Core samples – 9 cm diameter X 9 cm high
    - Triplicate cores from trench bottom and sidewall at 2 or 3 locations within drainfield
      - Gravel?, biomat, and natural soil
    - Triplicate cores from natural soil at equivalent depths – vertical and horizontal orientations

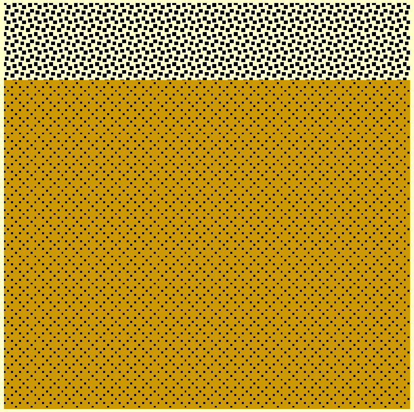

Dispersal Lines
Dispersal Trench
X
X
X
XXX
X
X
X

Sampling


Lab Methods

- K measured by constant head method
- Undisturbed samples collected from cores after K measurement
  - Impregnated with resin containing fluorescent additive
  - Polished blocks prepared by standard methods
  - Biomat thickness estimated from evaluation of porosity with depth by image analysis

Apply Theory to Data



$R_b = L_b/K_b$

$R_s = L_s/K_s$

K_{eff} – measured on cores

R_{eff} = total core length/K_{eff}

L_b – measured

L_s = core length - L_b

K_s – measured on separate sample

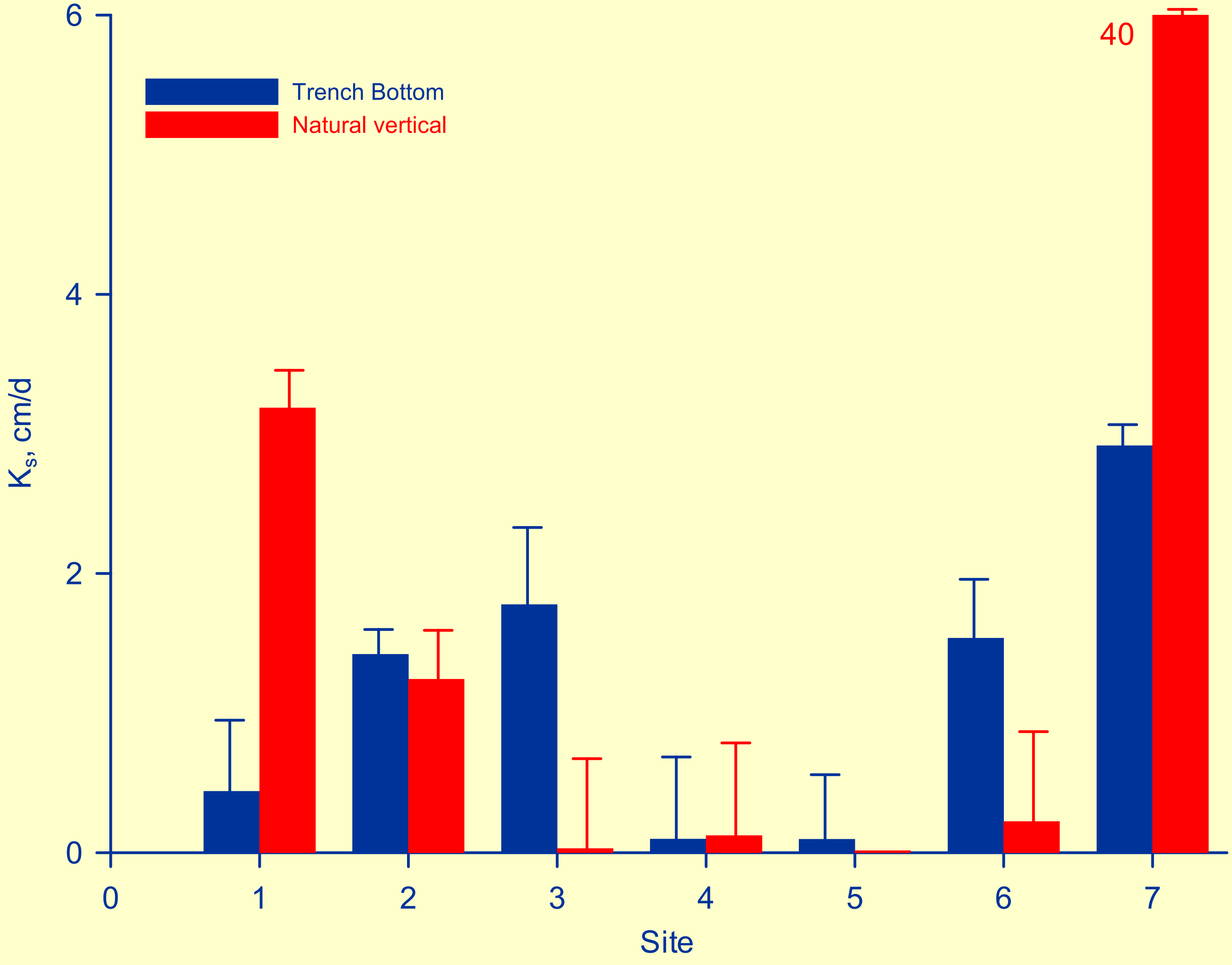
K_{eff} = total core length / (L_b/K_b + L_s/K_s)

K_b =

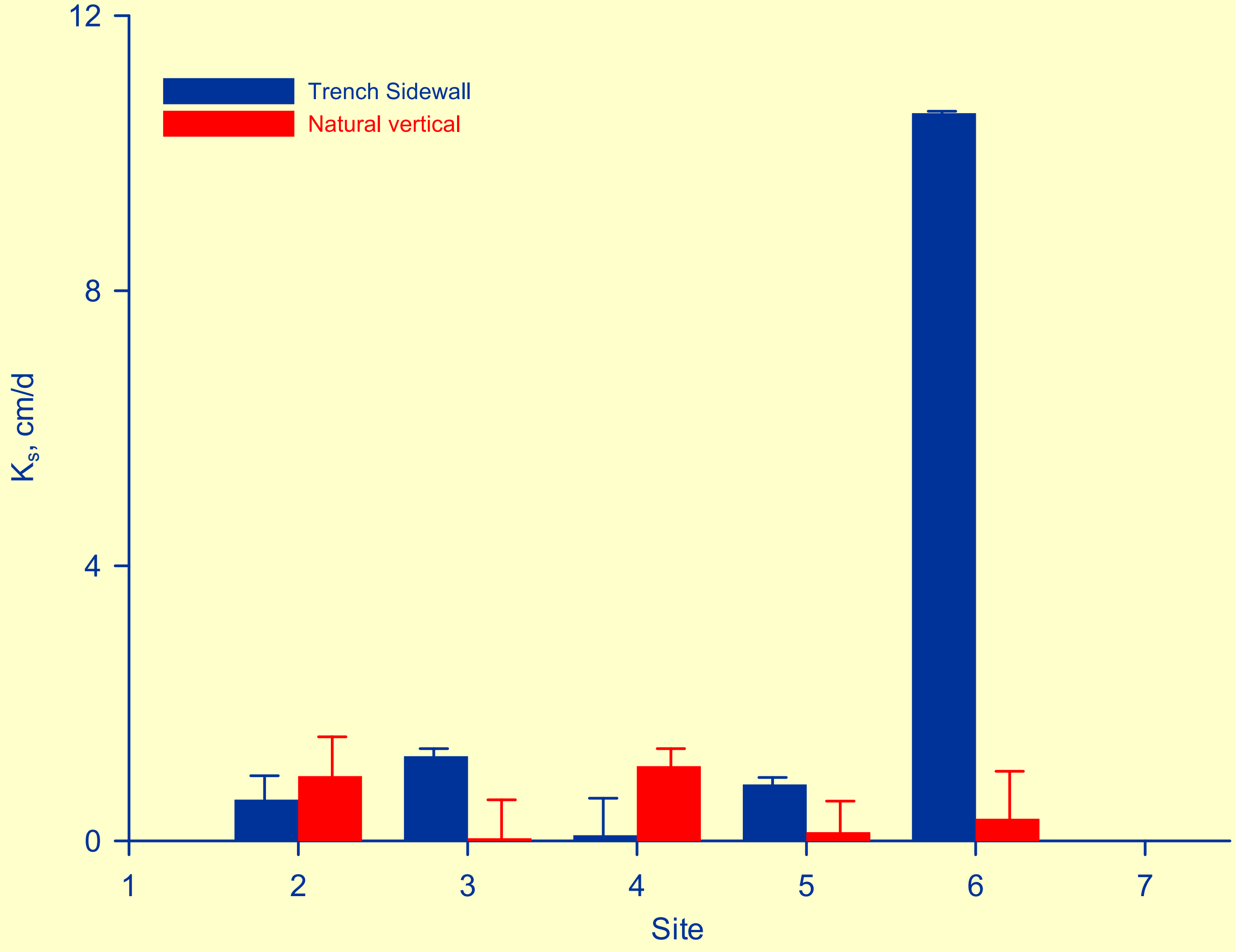
L_b / [(core length/K_{eff}) – (L_s/K_s)]

Results

Soil and Trench Bottom K



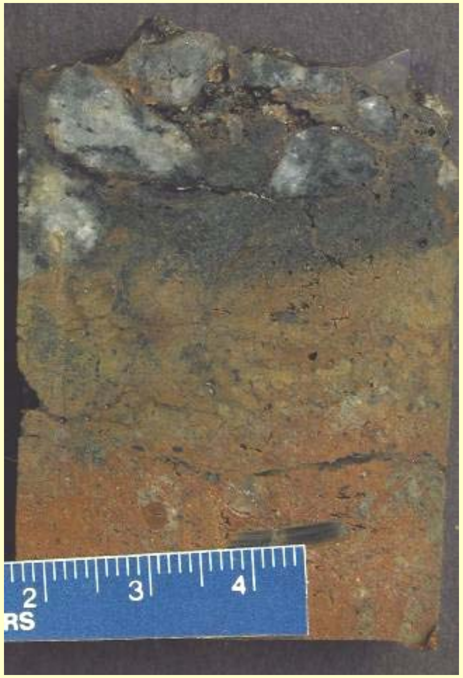
Soil and Trench Sidewall K



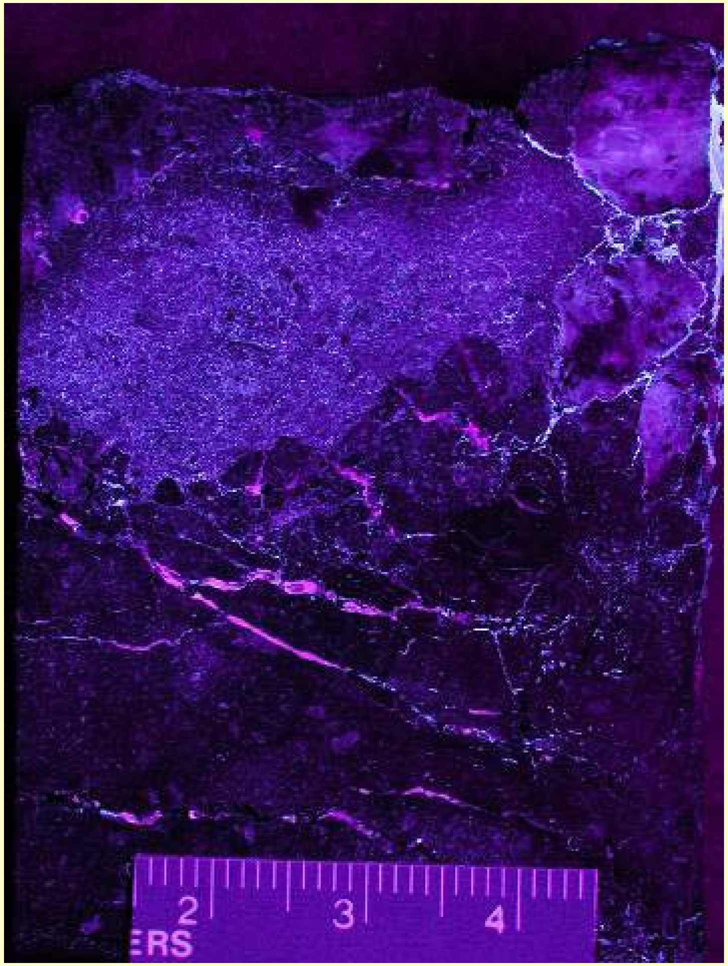
Soil K_s vs. Soil + Biomat K_{eff}

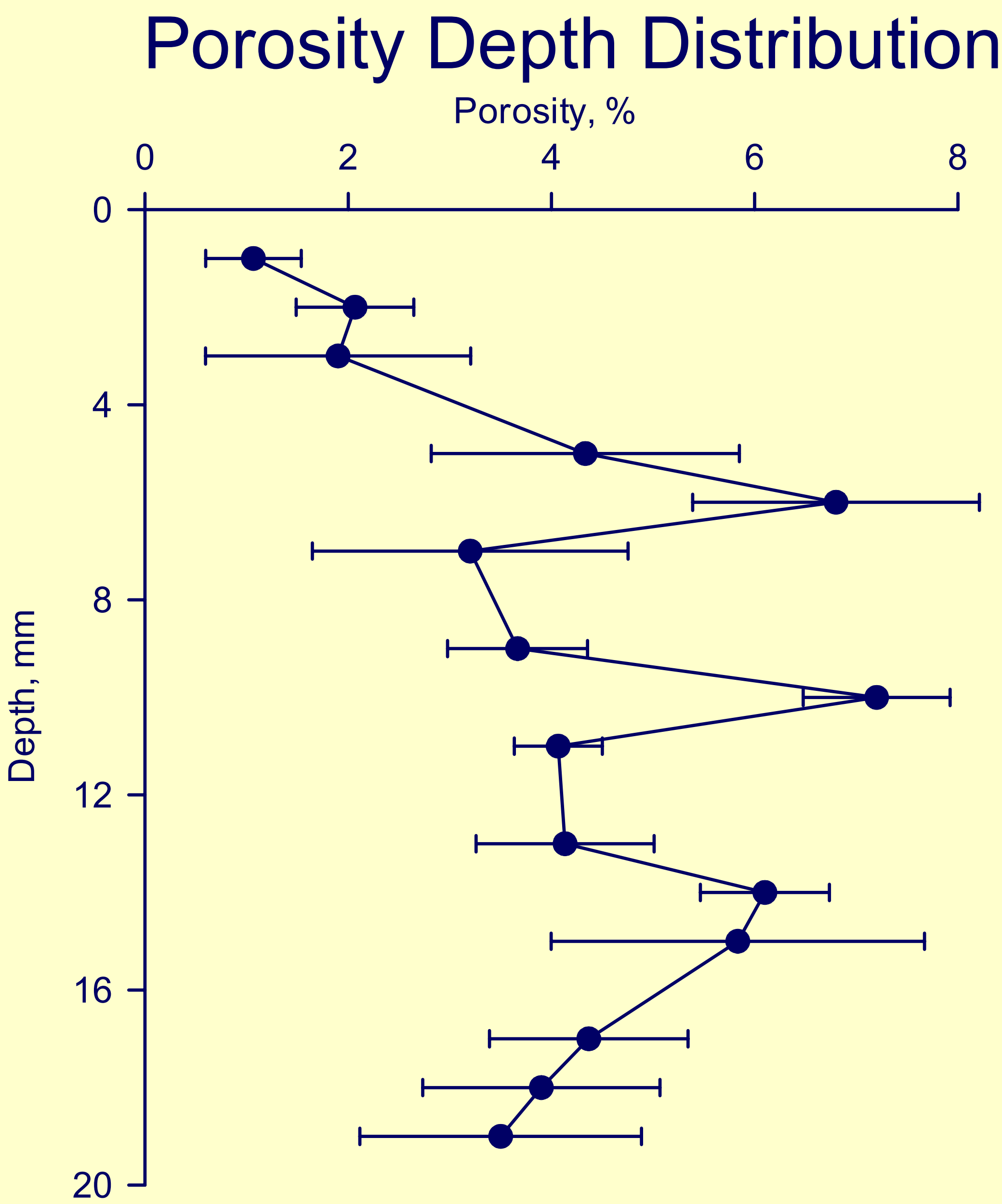
- Excluding Site 1 (3.2 cm/d), K_s of Piedmont soils ranged from 0 to 1.2 cm/d [mean = 0.4 cm/d (0.1 gpd/ft^2)]
  - Soils not suitable for onsite system
- Variability in K exceeded ability to measure biomat effect
  - Natural soil variability
  - Variability in wastewater loading
    - Serial distribution
    - Unlevel trench bottoms

Biomat Thickness

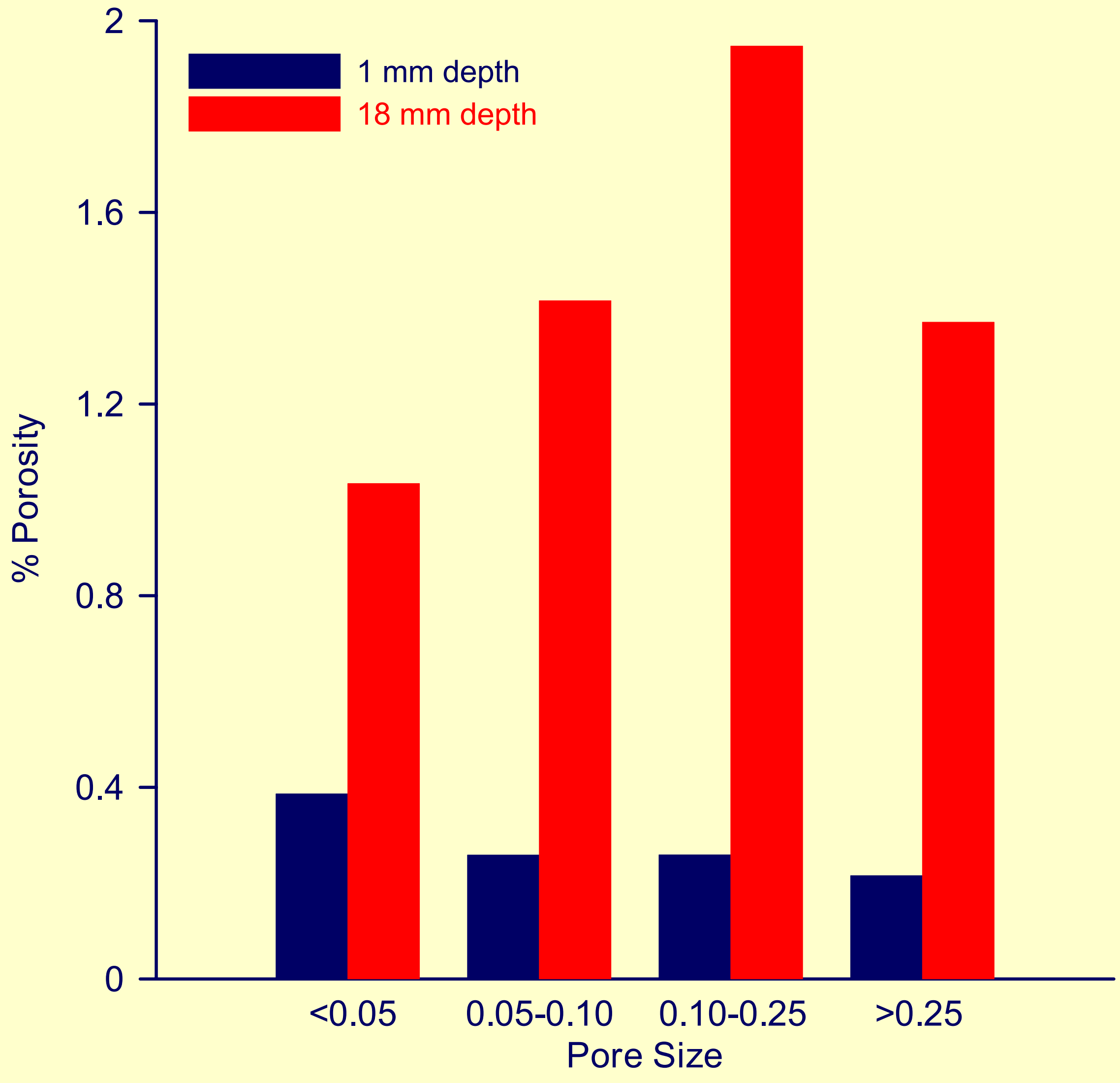


Biomat Thickness




Porosity Depth Distribution
Porosity, %
0
2
4
6
8
0
4
8
12
16
20
Depth, mm

Biomat Pore Size Distribution



Biomat Thickness

	Biomat Thickness (L_b)			
Site	Bottom	n	Sidewall	n
	cm		cm	
1	0.4	3	--	--
2	0.4	2	0.6	2
3	0.5	2	0.7	1
4	0.6	2	0.6	1
5	0.5	7	0.3	1
6	0.8	2	--	--
7	0.4	10	--	--
Mean	**0.5**		**0.5**	

Biomat K_s

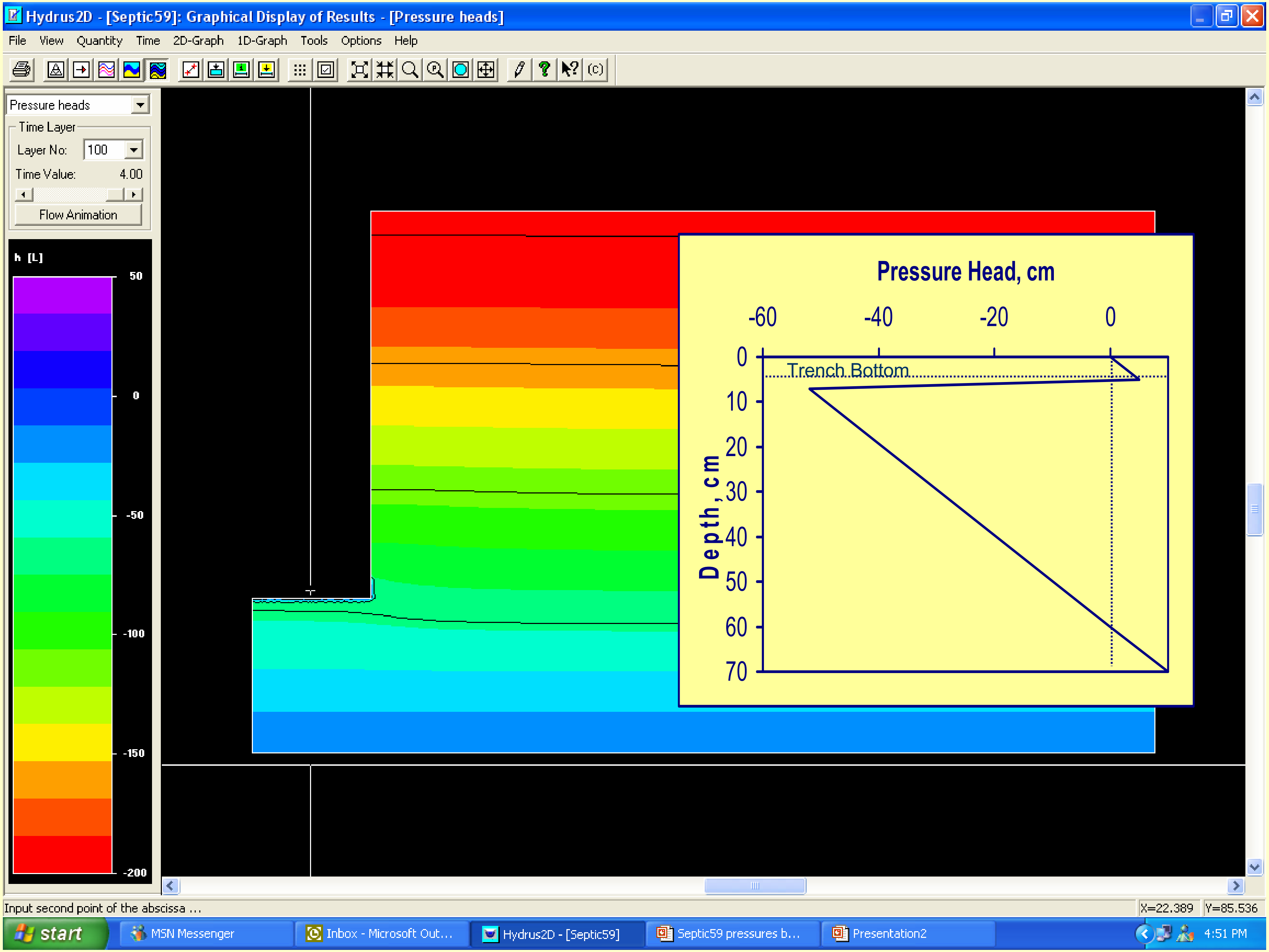
Site	Core K_{eff}	Soil K_s	Sign.	Biomat K_s
	cm/d	cm/d		cm/d
1	0.5	3.2	*	0.02
2	0.7	1.1	*	0.12
3	1.5	0.01	*	NA
4	0.1	0.4	NS	0.01
5	0.1	0.01	NS	0.05
6	2.7	0.3	*	NA
7	2.9	41	*	0.20
Mean				0.08

Biomat K_s – Relative to Soil K_s

Site	Soil K_s	Biomat K_s	Biomat K_s / Soil K_s
	cm/d	cm/d	%
1	3.2	0.02	0.6
2	1.1	0.12	11
4	0.4	0.01	2.5
5	0.01	0.05	--
7	41	0.20	0.5
Mean	9.1	0.08	0.9

Do the Numbers Apply?

- Soil K_s = 30 cm/d (7.5 gpd/ft^2)
- Soil thickness = 30 cm (12 inches)
- Biomat K_s = 0.6% of soil K_s
  = 30 * 0.006 = 0.18 cm/d
- Biomat Thickness = 0.5 cm
- R_{total} = $(L_b / K_{s\ bio}) + (L_{soil} / K_{s\ soil})$
  = 3.8 days
- K_{eff} = L_{total} / R_{total}
  = 30.5 / 3.8
  = 8.0 cm/d (2 gpd/ft^2)
- Assumes soil is saturated – probably not


Hydrus2D - [Septic59]: Graphical Display of Results - [Pressure heads]
File View Quantity Time 2D-Graph 1D-Graph Tools Options Help
Pressure heads
Time Layer
Layer No: 100
Time Value: 4.00
Flow Animation
h [L]
50
0
-50
-100
-150
-200
Pressure Head, cm
-60 -40 -20 0
Trench Bottom
Depth, cm
0 10 20 30 40 50 60 70
Input second point of the abscissa ...
X=22.389 Y=85.536
start
MSN Messenger
Inbox - Microsoft Out...
Hydrus2D - [Septic59]
Septic59 pressures b...
Presentation2
4:51 PM

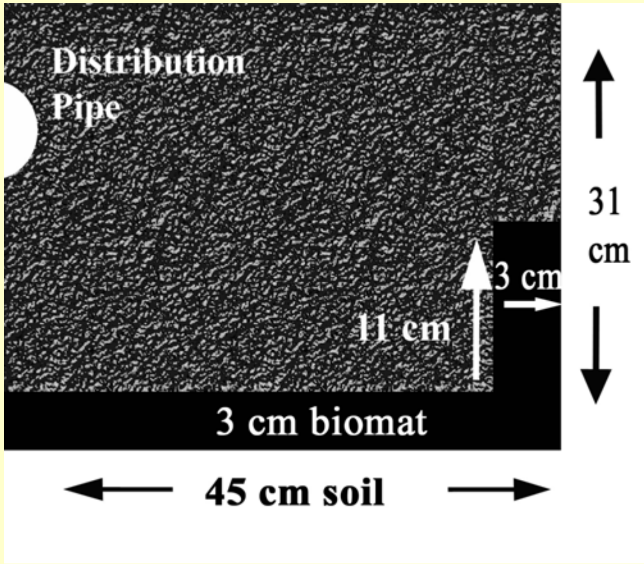
If the Soil is Unsaturated

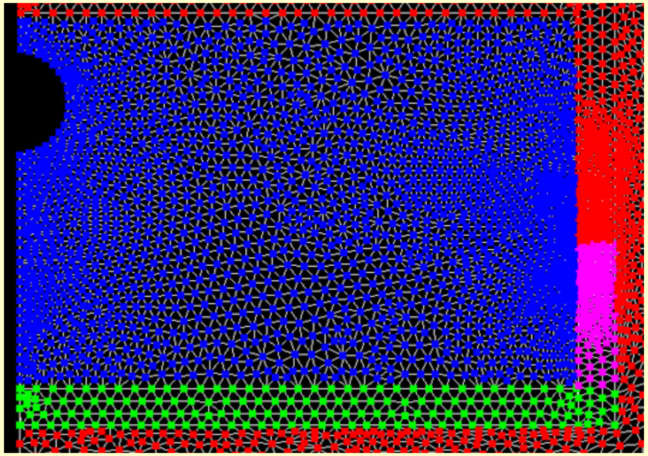
- Soil K_s = 30 cm/d (7.5 gpd/ft^2)
- Soil K_{unsat} = 3 cm/d (0.8 gpd/ft^2)
- Soil thickness = 30 cm (12 inches)
- Biomat K_s = 0.6% of soil K_s
  = 30 * 0.006 = 0.18 cm/d
- Biomat Thickness = 0.5 cm
- R_{total} = $(L_b / K_{s\ bio}) + (L_{soil} / K_{unsat\ soil})$
  = 12.8 days
- K_{eff} = L_{total} / R_{total}
  = 30.5 / 12.8
  = 2.4 cm/d (0.6 gpd/ft^2)
- Gradients have not been considered

Does Sidewall Flow Occur?

Model Simulations

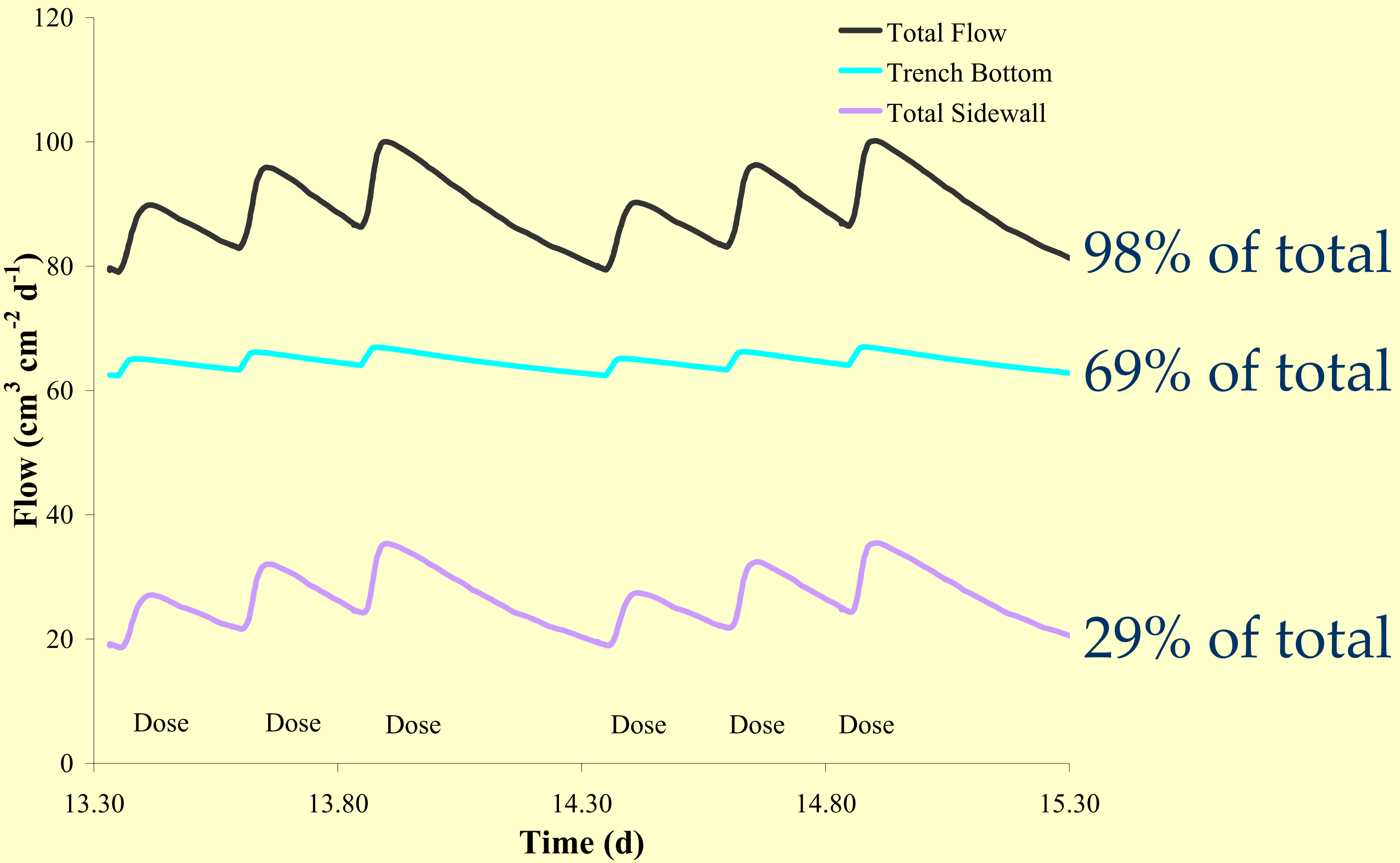
- HYDRUS – 2D
- Soil in equilibrium with water table at 60 cm below trench
- 3 cm thick biomat on bottom and lower 11 cm of sidewall
  - Biomat resistance from measured data
- Wastewater applied in 3 equal doses (2 cm/d)
- Simulation run until equilibrium; 13 days



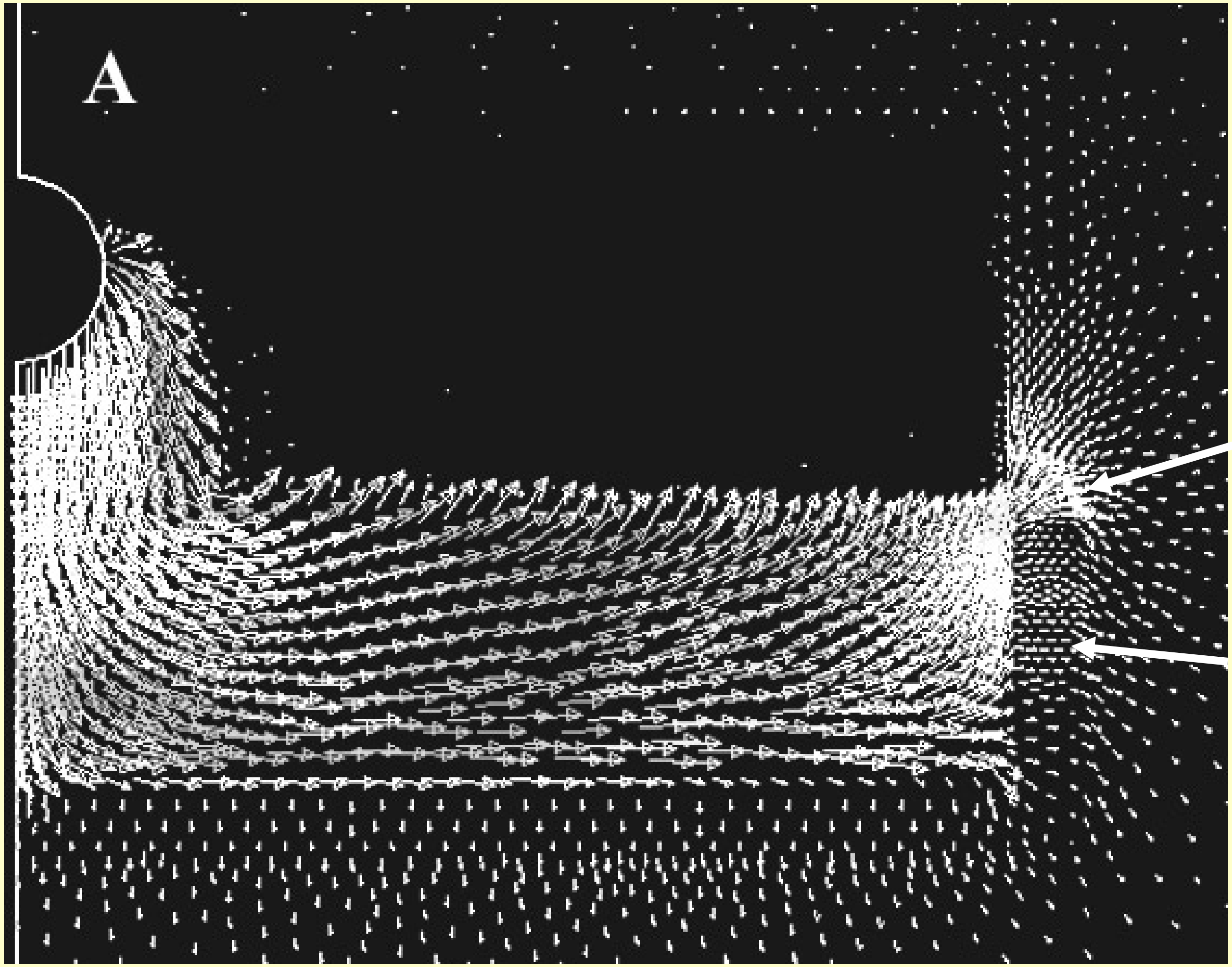


Ponding Depth

Bottom and Sidewall Flow



Bottom and Sidewall Flow



45% of sidewall flow

55% of sidewall flow

Summary

- Biomat effect on K of slowly permeable soils was difficult to measure
- K_{eff} of trench bottom and sidewall similar
  - Sidewall samples from lower part of sidewall
- Mean biomat thickness as measured by porosity reduction = 0.5 cm
- Mean biomat K_s = 0.08 cm/d
  - $<1\%$ of soil K_s
- Model simulation for soil w/ low permeability
  - 30% of flow through sidewall
  - 45% of sidewall flow through thin zone above biomat