A Simple Method for Estimating Design Hydraulic Loading Rates in OWSs[1]

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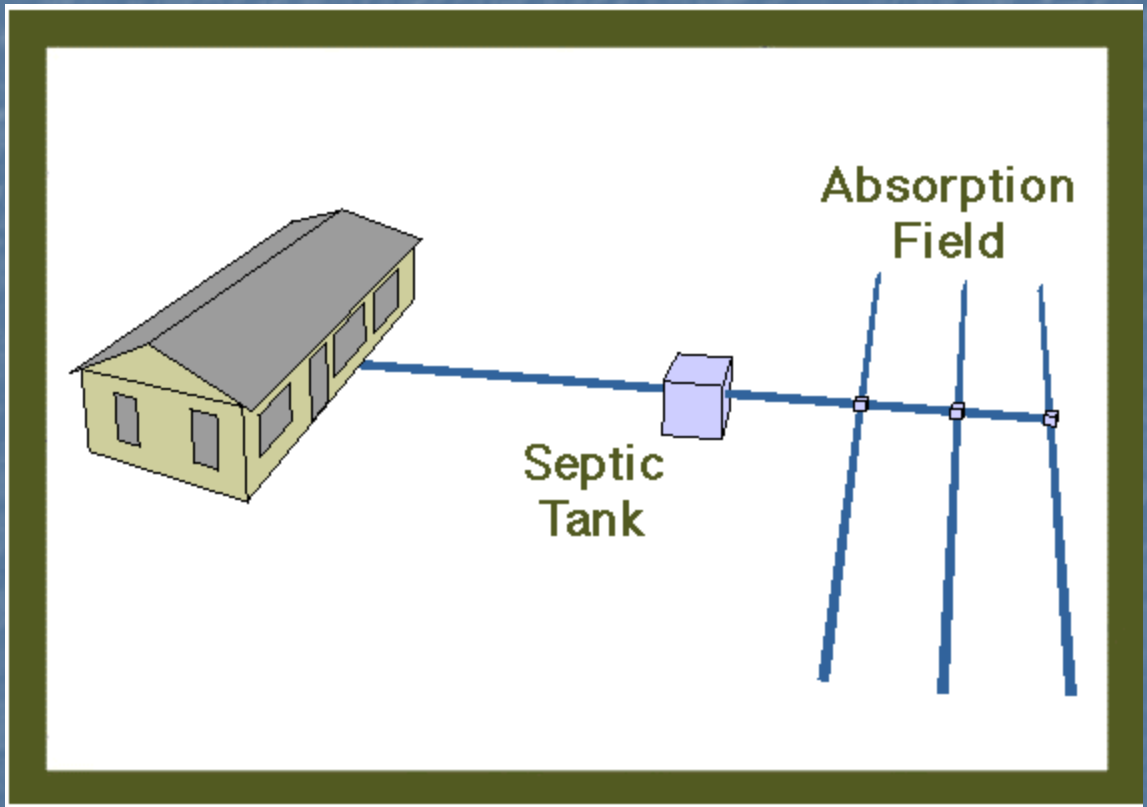
University of Georgia

[1]Presented at the CSREES National Water Conference, February 3-7, 2008, Reno NV

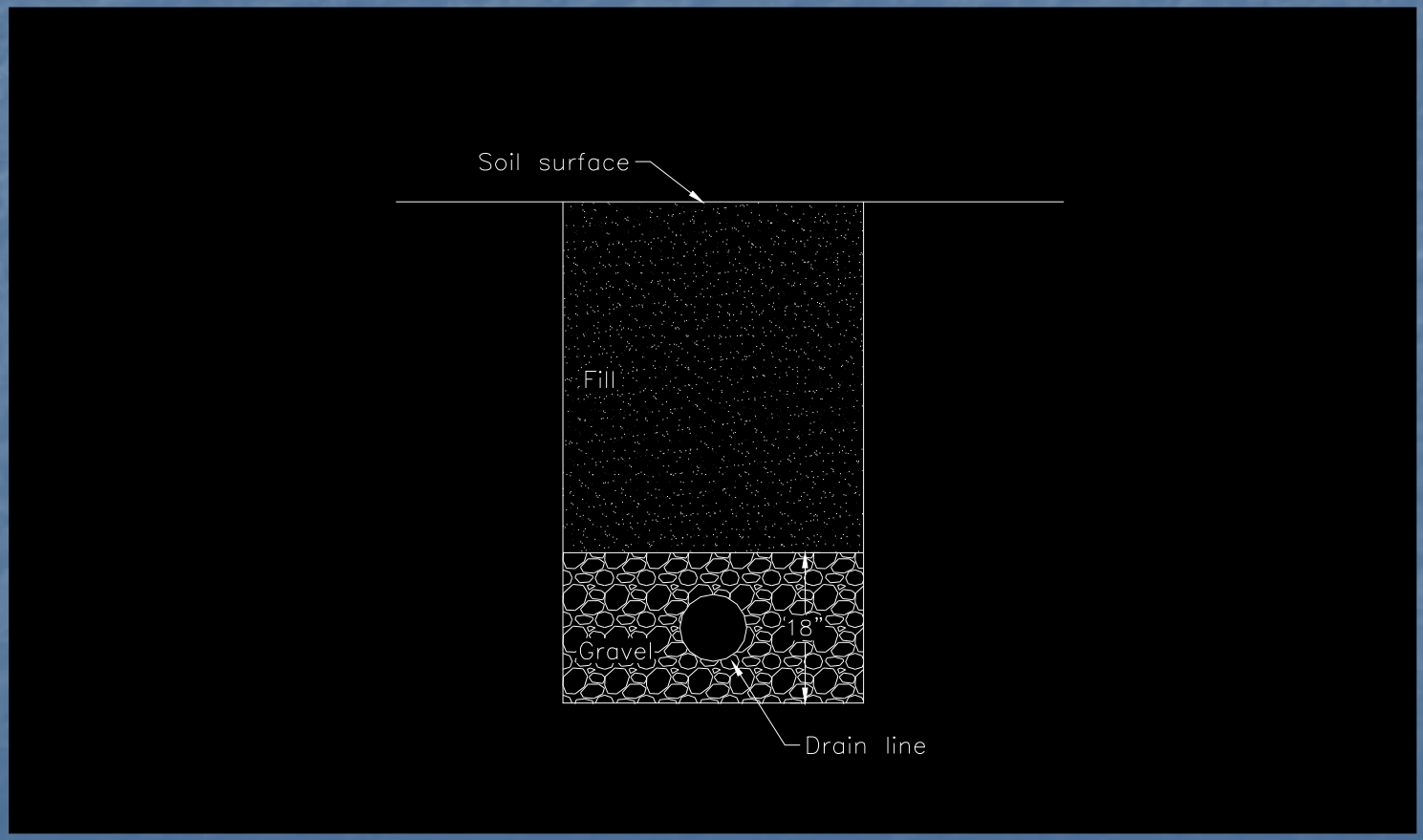
Onsite Wastewater Systems



Septic tank with drainfield. Perforated pipe in the drainfield allows the soil to absorb treated effluent.

75% of new homes in Georgia are on OWSs

Absorption Field Trench



Design Hydraulic Loading Rate

- Wastewater infiltration rates decline over time due to formation of a biomat
- Estimate of final infiltration rate needed to determine design hydraulic loading rate (HLR_D)
  - Trench line length based on estimate of HLR_D
- Also referred to as Long Term Acceptance Rate (LTAR)
  - LTAR includes effect of organic loading rate
  - Do not consider organic loading rate in this analysis

Design Hydraulic Loading Rate

- Siegrist (2007)
  - HLR_D varies widely among states & often based on empirical evidence
  - Need more rational and uniform approach to estimate HLR_D
  - HLR_D should be based on trench bottom flux under shallow ponding conditions (normal loading)
    - Reserve trench volume and sidewall flux for peak flow (peak loading)
  - Use computer models to aide design

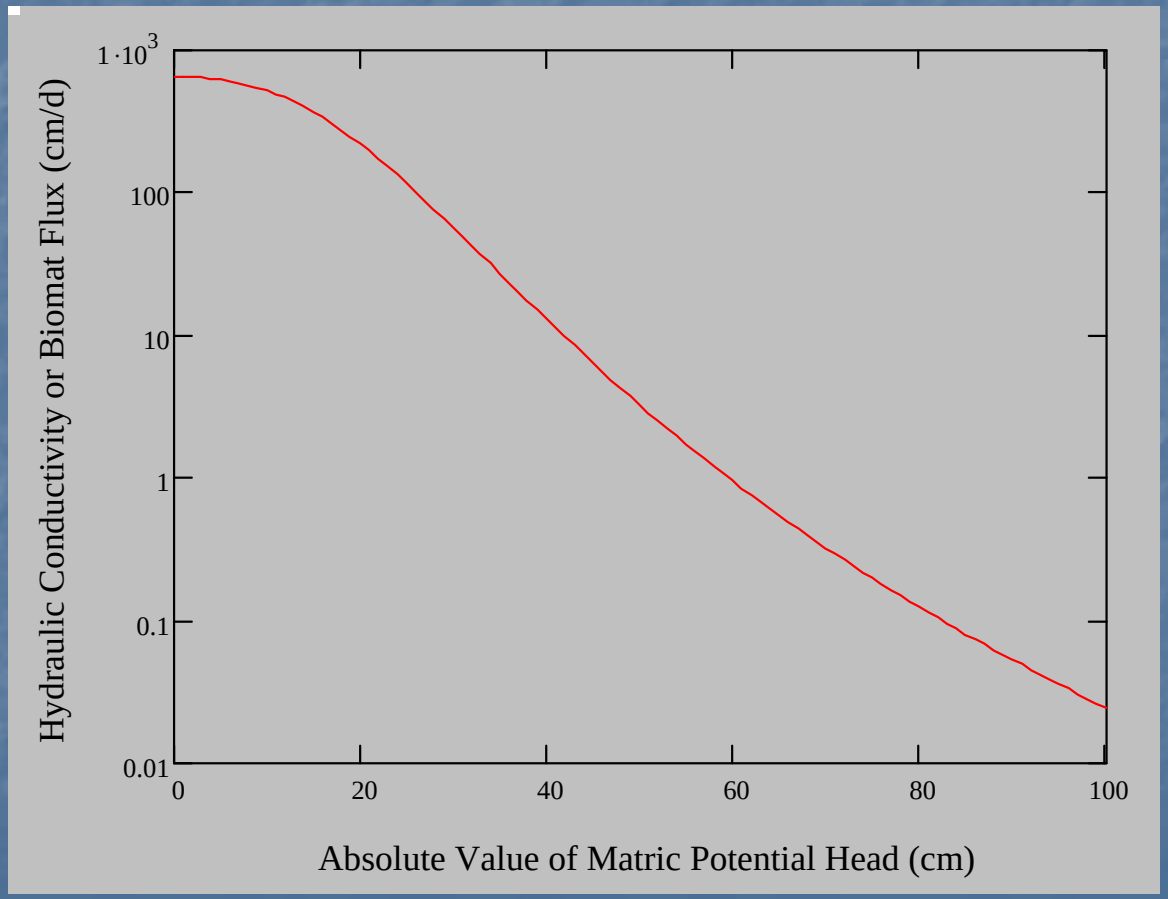
Bouma Equation

- Bouma (1975) developed simple equation for estimating trench bottom flux

$$K_{bs}\frac{h_0 - h_s + Z_b}{Z_b} = K(h_s)$$

  - K_{bs} = biomat saturated hydraulic conductivity
  - Z_b = biomat thickness
  - h_0 = height of ponding in trench
  - h_s = soil matric potential below biomat
  - $K(h_s)$ = soil unsaturated hydraulic conductivity below biomat

Bouma Equation



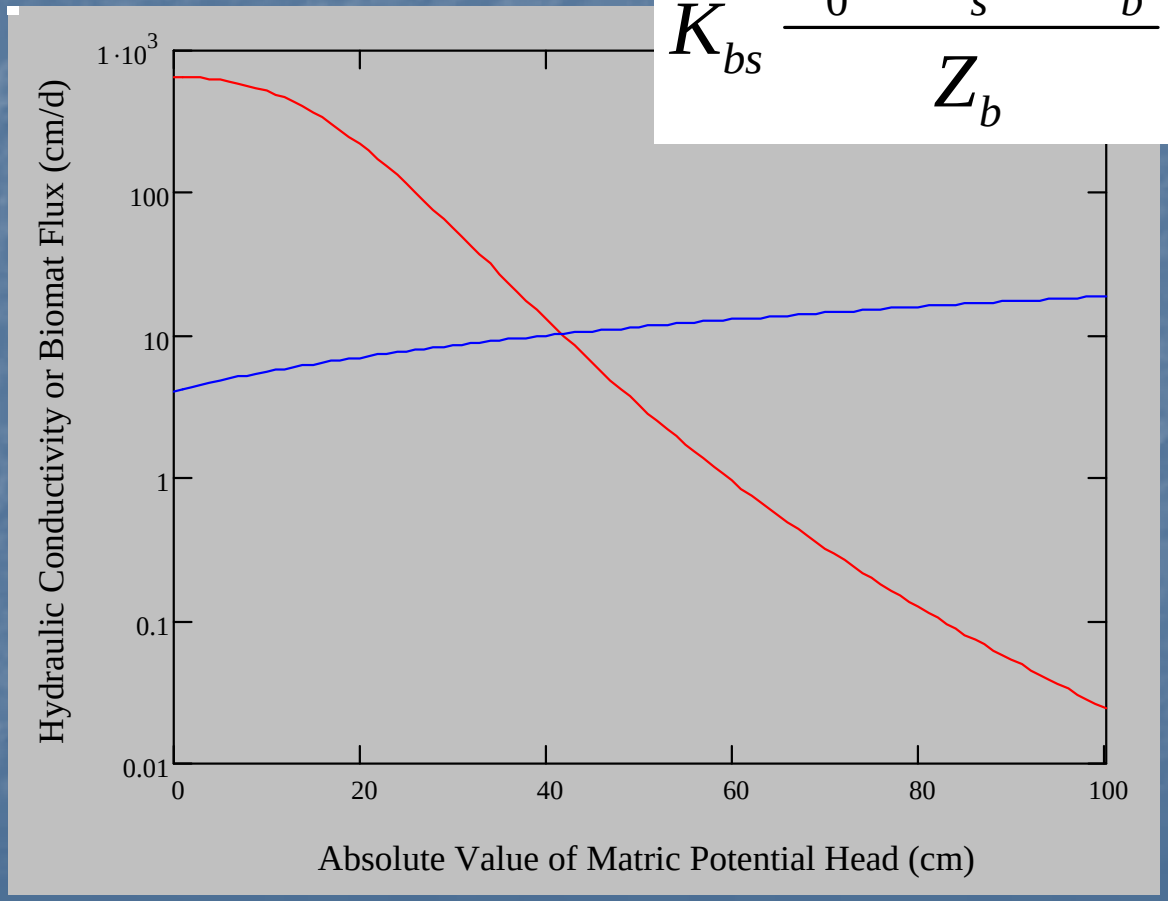
$K(h_s)$

?

Bouma Equation

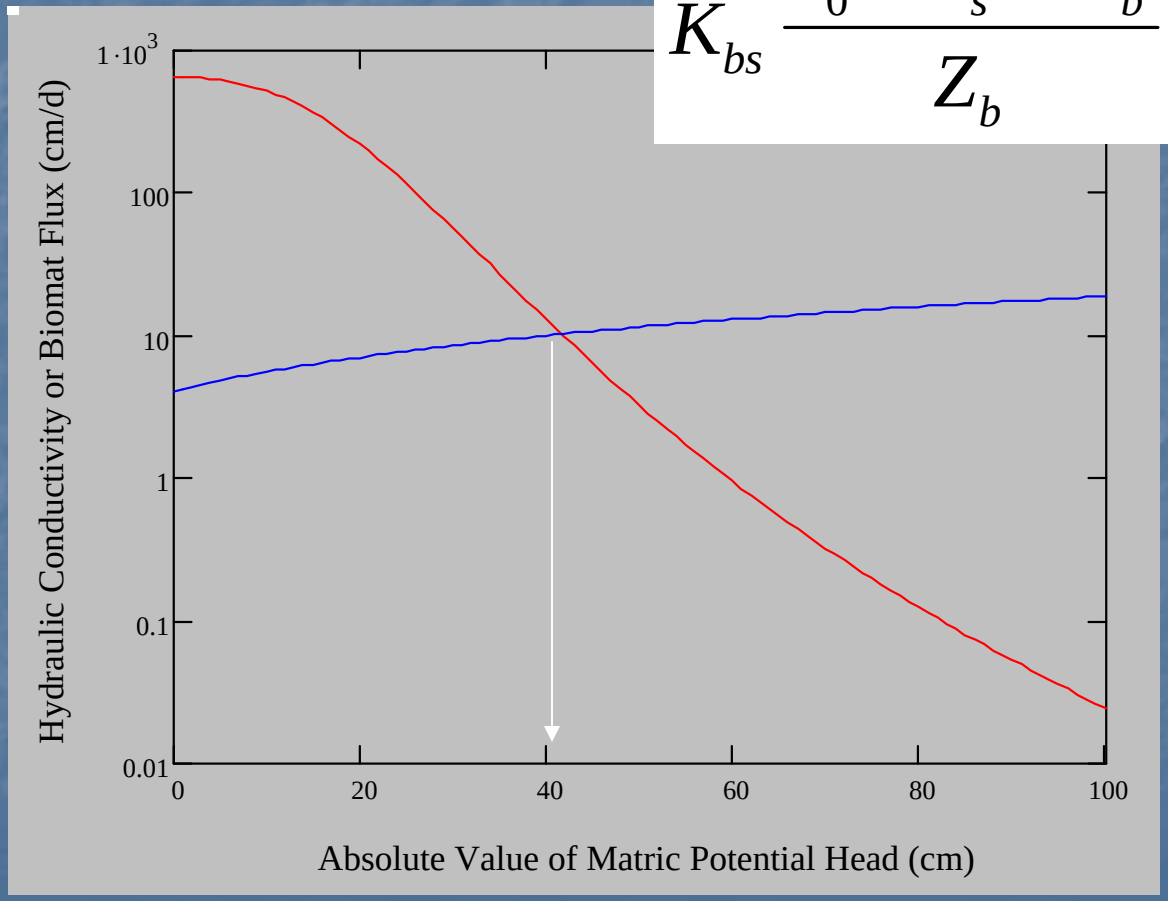
?

$$K_{bs} \frac{h_0 - h_s + Z_b}{Z_b}$$



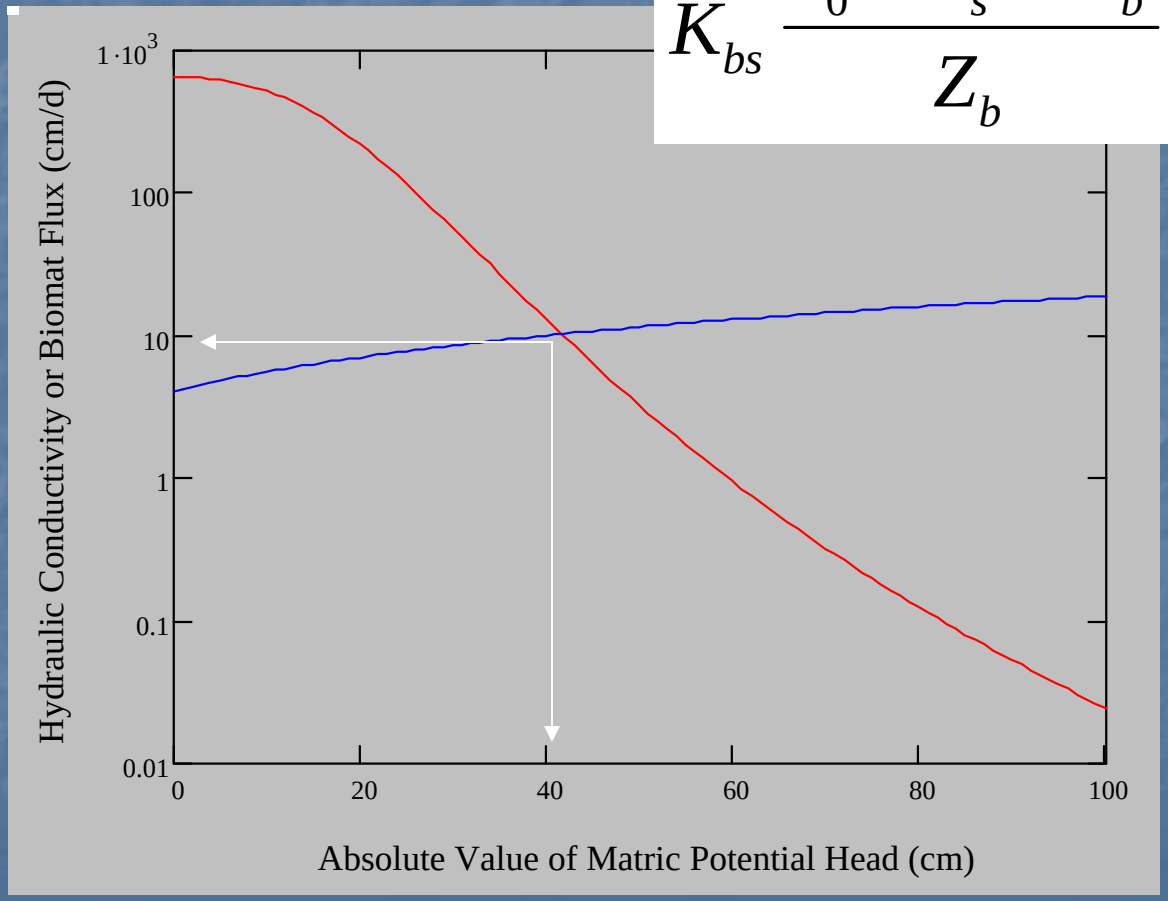
Bouma Equation

$$K_{bs}\,\frac{h_0 - h_s + Z_b}{Z_b} = K(h_s)$$



Bouma Equation

$$K_{bs}\,\frac{h_0 - h_s + Z_b}{Z_b} = K(h_s)$$



Objectives

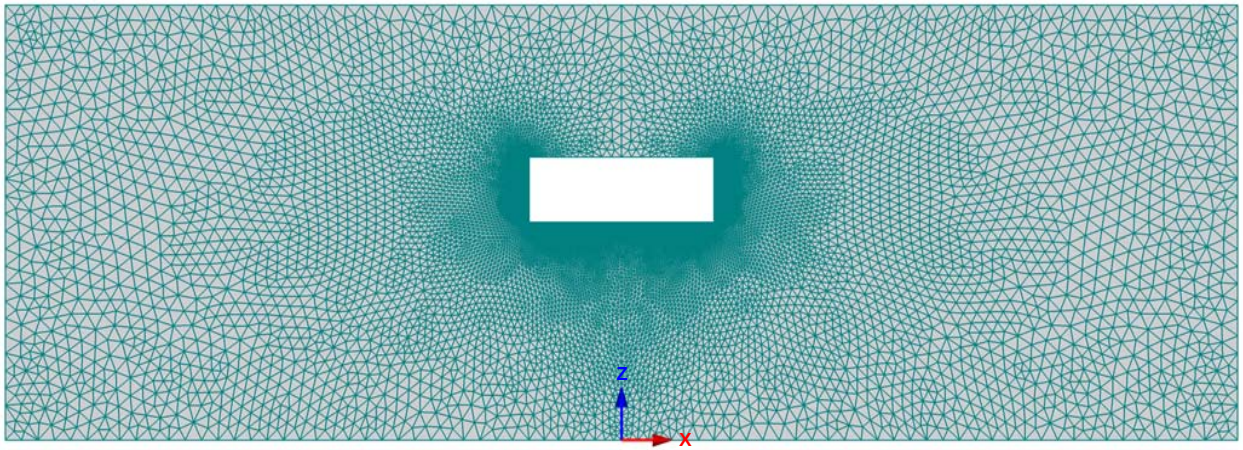
- Develop simple method for estimating HLR_D based on soil and biomat hydraulic properties
  - Use Bouma equation to estimate trench bottom flux under shallow ponding for 12 soil textural classes
  - Compare Bouma equation estimates to 2D computer model (HYDRUS)
  - Take ½ flux as estimate of HLR_D (safety factor of 2)
  - Compare estimates of HLR_D to classification systems that have been proposed

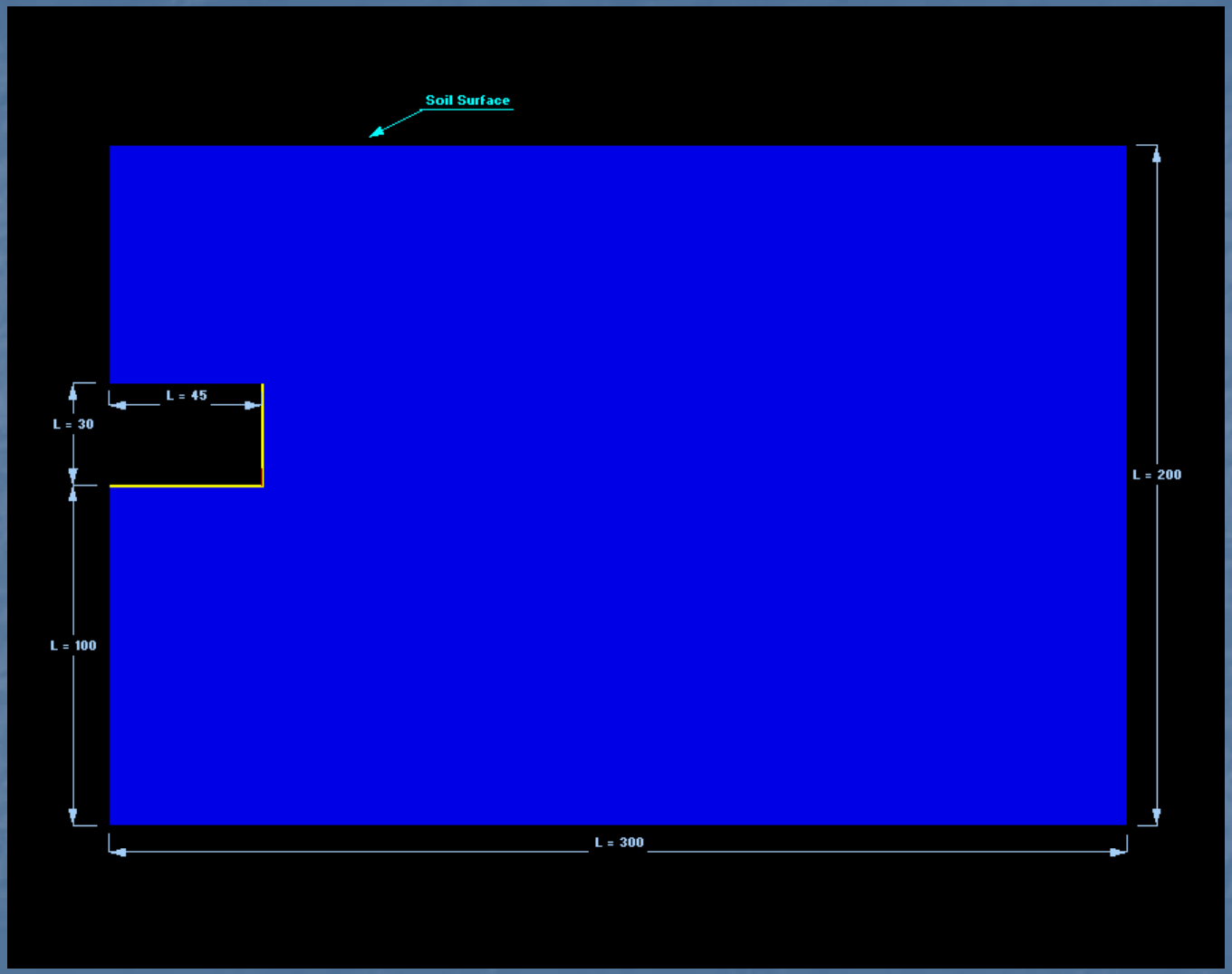
Soil textural class	K_s	n	α	θ_r	θ_s
	cm d^{-1}		cm^{-1}	cm^3 cm^{-3}	
Sand	642.98	3.18	0.0353	0.053	0.375
Loamy sand	105.12	1.75	0.0347	0.049	0.390
Silt	43.74	1.68	0.0066	0.050	0.489
Sandy loam	38.25	1.45	0.0267	0.039	0.387
Silt loam	18.26	1.66	0.0051	0.065	0.439
Clay	14.75	1.25	0.0150	0.098	0.459
Sandy clay loam	13.19	1.33	0.0211	0.063	0.384
Loam	12.04	1.47	0.0111	0.061	0.399
Sandy clay	11.35	1.21	0.0334	0.117	0.385
Silty clay loam	11.11	1.52	0.0084	0.090	0.482
Silty clay	9.61	1.32	0.0162	0.111	0.481
Clay loam	8.18	1.41	0.0158	0.079	0.442

From Rosetta Lite database in HYDRUS

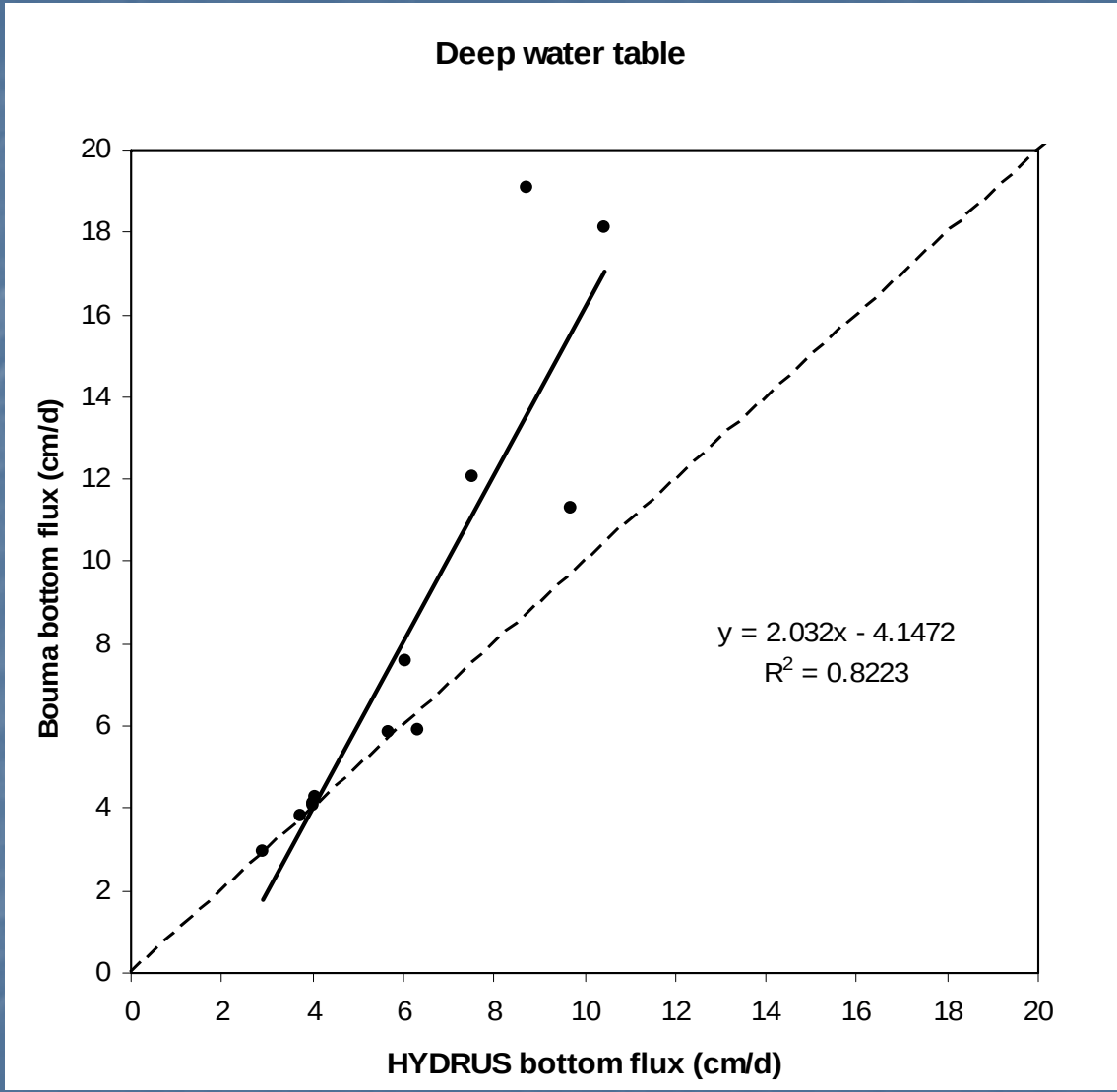
Biomat Properties

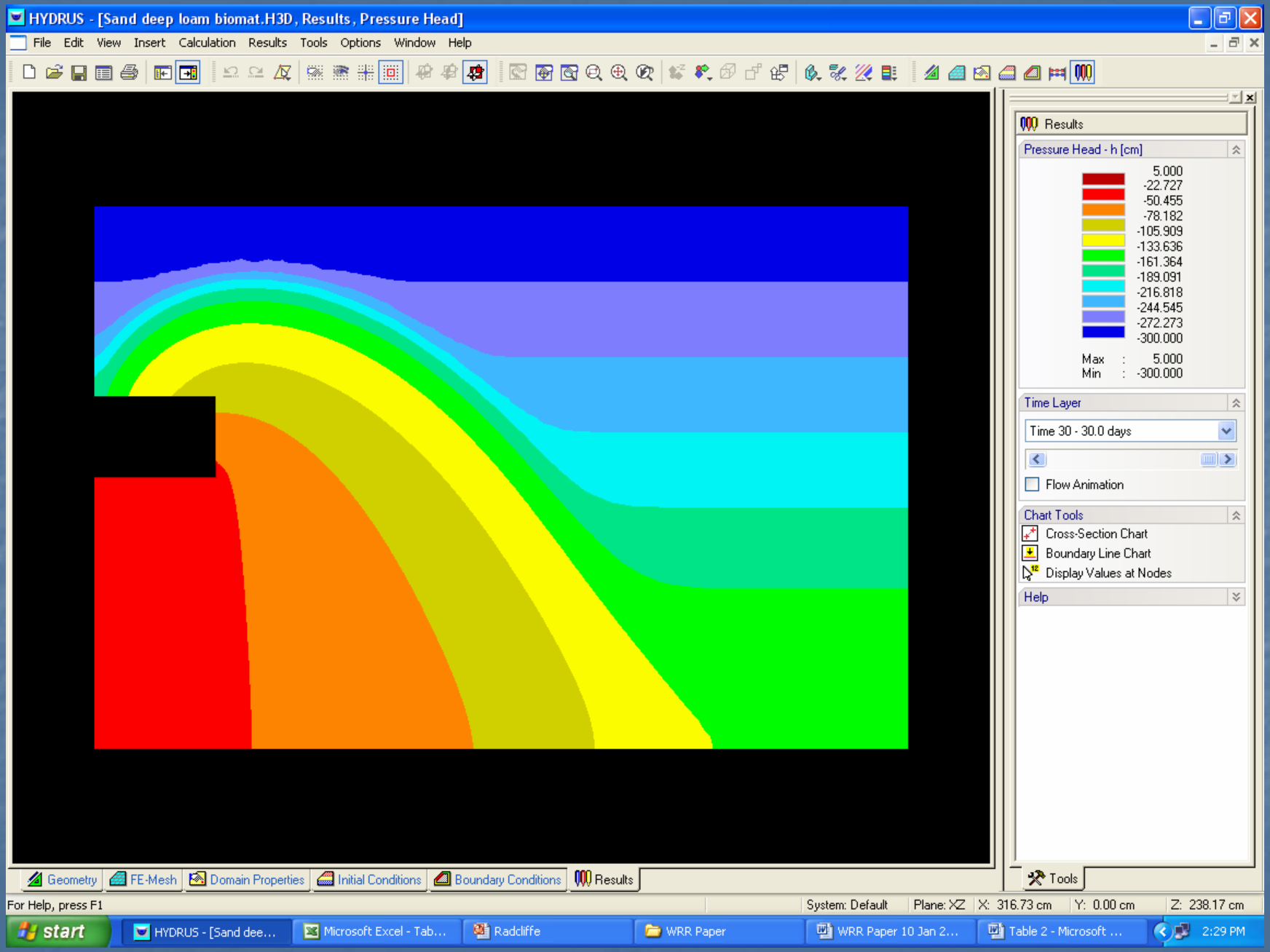
- Finch et al (2007)
  - Measurements from 6 OWS sites in Georgia
  - Biomat average thickness (Z_b) = 0.5 cm
  - Biomat average saturated hydraulic conductivity (K_{bs}) = 0.23 cm/day
- We assumed a loam texture for biomat in all simulations

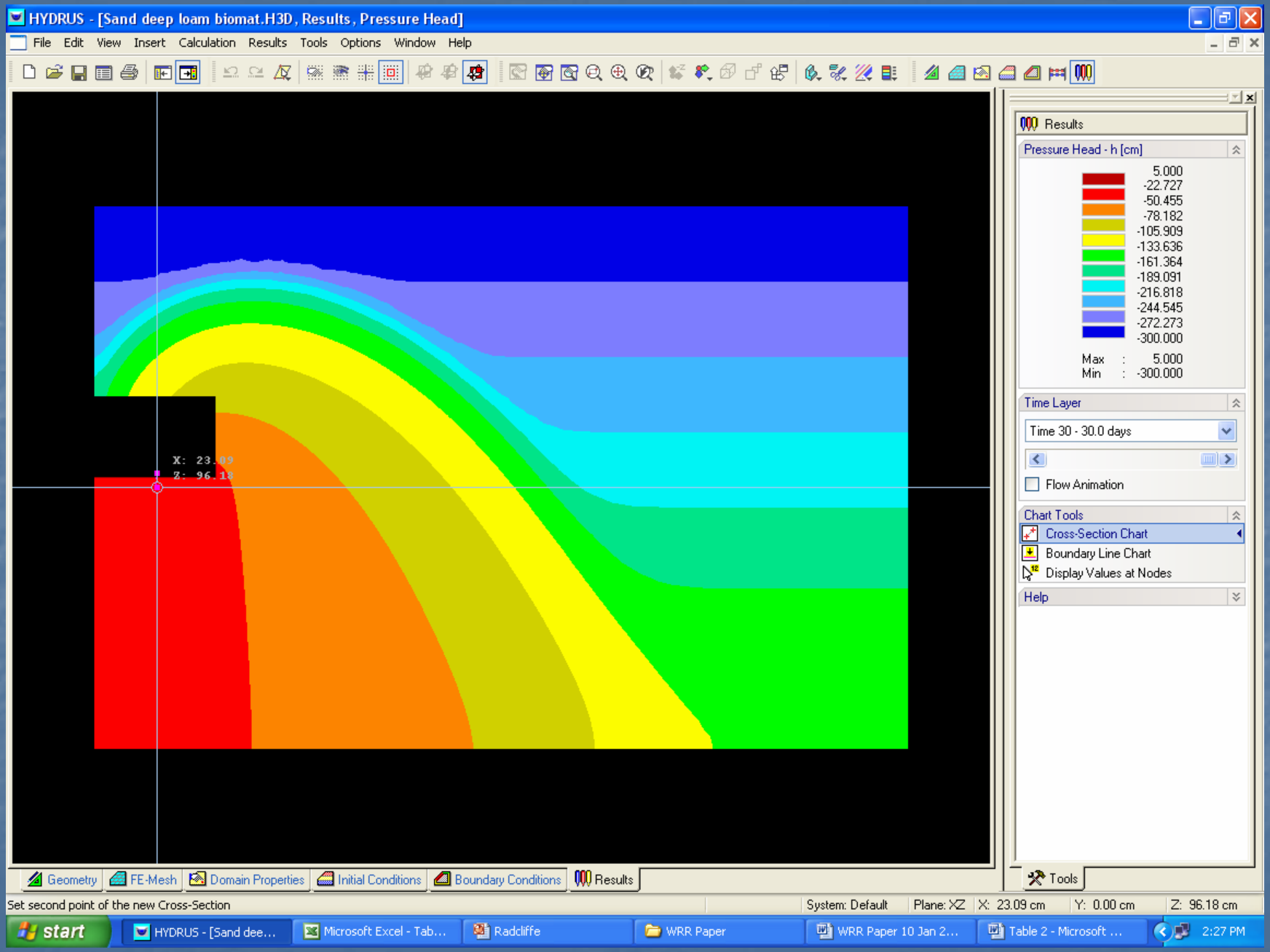

Z
X

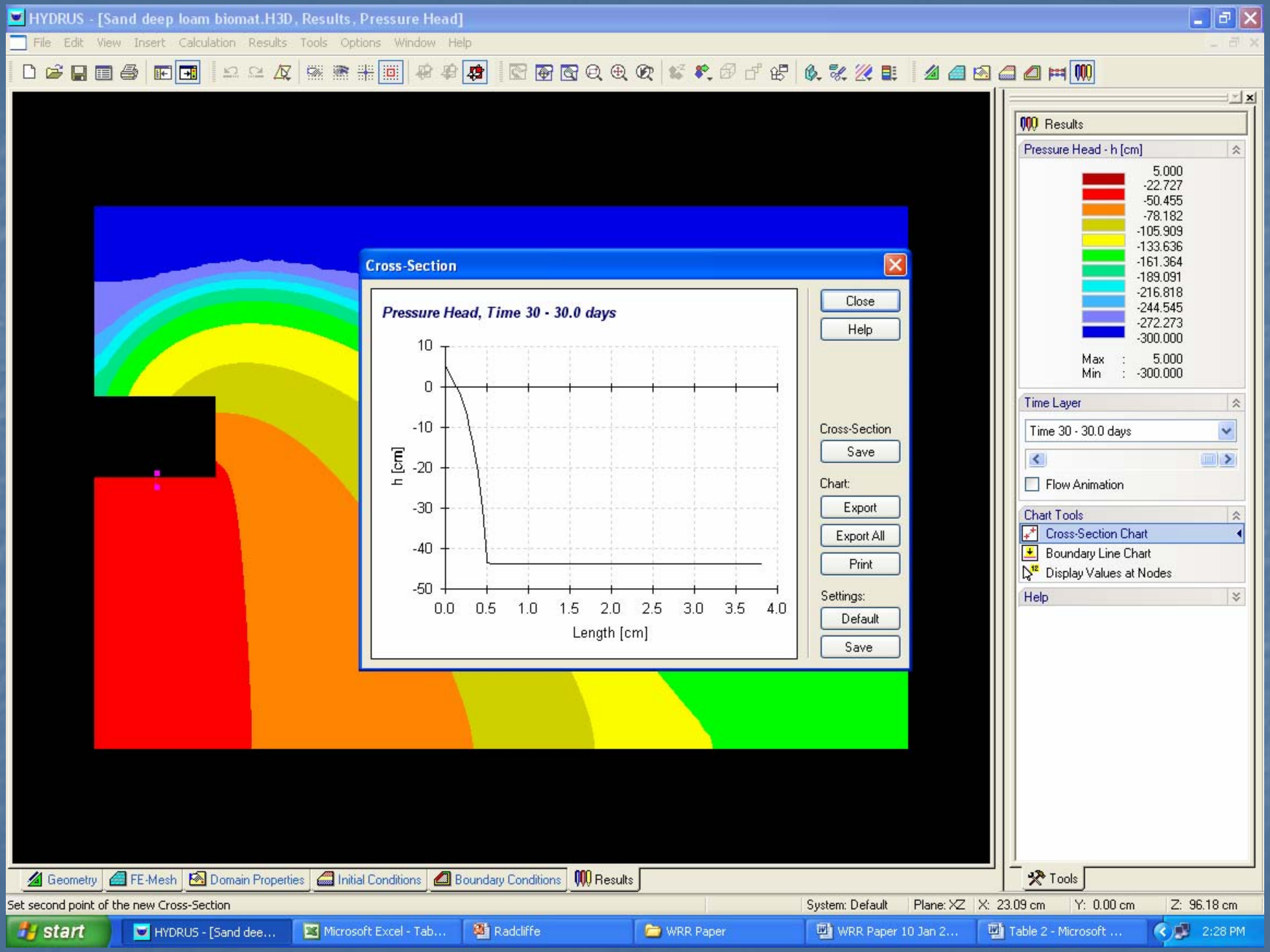


Water Content - th[-], Min=0.055, Max=0.399


Deep water table
Bouma bottom flux (cm/d)
HYDRUS bottom flux (cm/d)
y = 2.032x - 4.1472
R2 = 0.8223
0
2
4
6
8
10
12
14
16
18
20


HYDRUS - [Sand deep loam biomat.H3D, Results, Pressure Head]
File Edit View Insert Calculation Results Tools Options Window Help
Results
Pressure Head - h [cm]
5.000
-22.727
-50.455
-78.182
-105.909
-133.636
-161.364
-189.091
-216.818
-244.545
-272.273
-300.000
Max : 5.000
Min : -300.000
Time Layer
Time 30 - 30.0 days
Flow Animation
Chart Tools
Cross-Section Chart
Boundary Line Chart
Display Values at Nodes
Help
Tools
Geometry
FE-Mesh
Domain Properties
Initial Conditions
Boundary Conditions
Results
For Help, press F1
System: Default
Plane: XZ
X: 316.73 cm
Y: 0.00 cm
Z: 238.17 cm
start
HYDRUS - [Sand dee...
Microsoft Excel - Tab...
Radcliffe
WRR Paper
WRR Paper 10 Jan 2...
Table 2 - Microsoft ...
2:29 PM


HYDRUS - [Sand deep loam biomat.H3D, Results, Pressure Head]
File Edit View Insert Calculation Results Tools Options Window Help
X: 23.09
Z: 96.18
Results
Pressure Head - h [cm]
5.000
-22.727
-50.455
-78.182
-105.909
-133.636
-161.364
-189.091
-216.818
-244.545
-272.273
-300.000
Max : 5.000
Min : -300.000
Time Layer
Time 30 - 30.0 days
Flow Animation
Chart Tools
Cross-Section Chart
Boundary Line Chart
Display Values at Nodes
Help
Geometry
FE-Mesh
Domain Properties
Initial Conditions
Boundary Conditions
Results
Tools
Set second point of the new Cross-Section
System: Default
Plane: XZ
X: 23.09 cm
Y: 0.00 cm
Z: 96.18 cm
start
HYDRUS - [Sand dee...
Microsoft Excel - Tab...
Radcliffe
WRR Paper
WRR Paper 10 Jan 2...
Table 2 - Microsoft ...
2:27 PM


HYDRUS - [Sand deep loam biomat.H3D, Results, Pressure Head]
File Edit View Insert Calculation Results Tools Options Window Help
Cross-Section
Pressure Head, Time 30 - 30.0 days
h [cm]
10
0
-10
-20
-30
-40
-50
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
Length [cm]
Close
Help
Cross-Section
Save
Chart:
Export
Export All
Print
Settings:
Default
Save
Results
Pressure Head - h [cm]
5.000
-22.727
-50.455
-78.182
-105.909
-133.636
-161.364
-189.091
-216.818
-244.545
-272.273
-300.000
Max : 5.000
Min : -300.000
Time Layer
Time 30 - 30.0 days
Flow Animation
Chart Tools
Cross-Section Chart
Boundary Line Chart
Display Values at Nodes
Help
Geometry
FE-Mesh
Domain Properties
Initial Conditions
Boundary Conditions
Results
Tools
Set second point of the new Cross-Section
System: Default
Plane: XZ
X: 23.09 cm
Y: 0.00 cm
Z: 96.18 cm
start
HYDRUS - [Sand dee...
Microsoft Excel - Tab...
Radcliffe
WRR Paper
WRR Paper 10 Jan 2...
Table 2 - Microsoft ...
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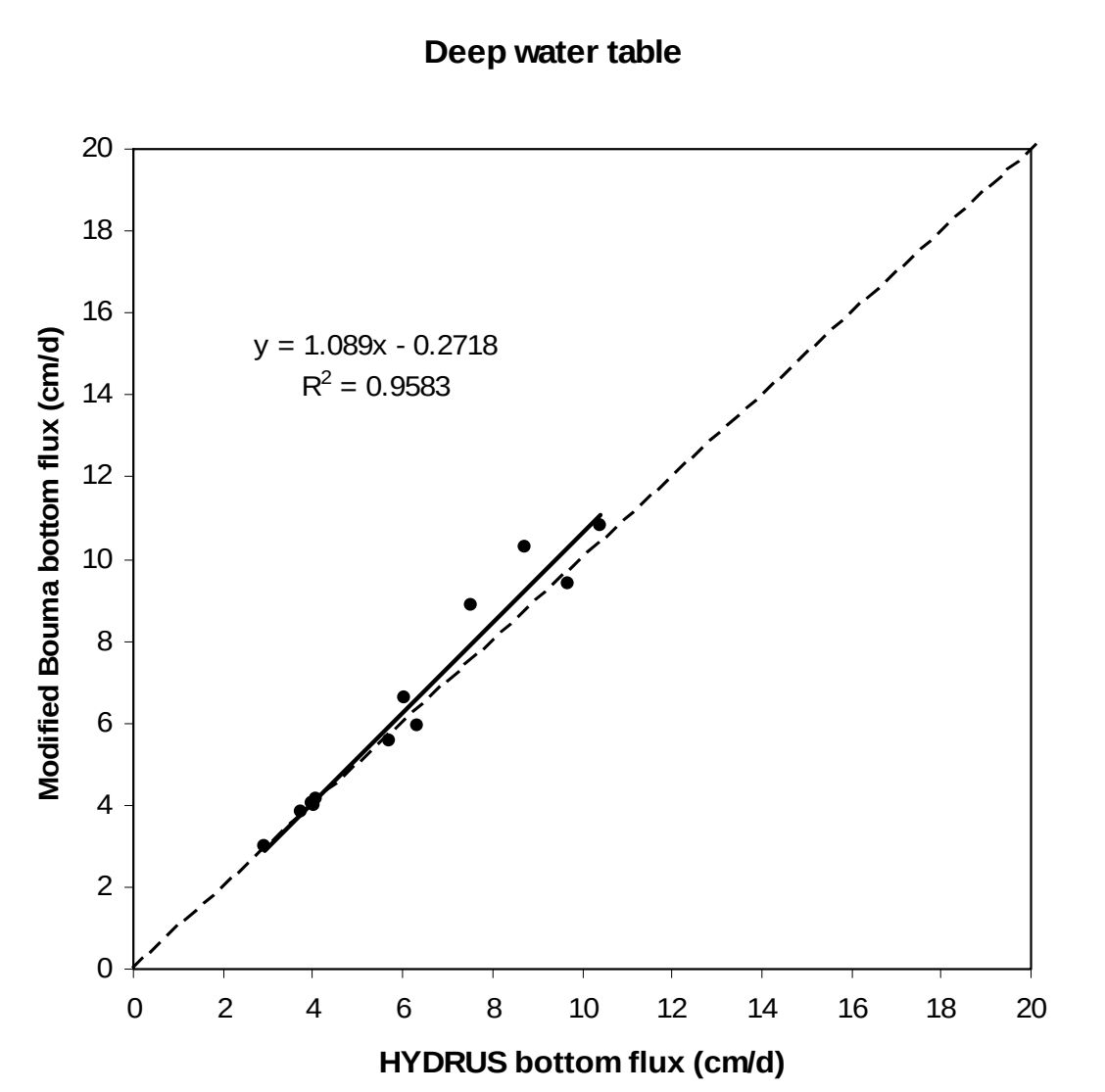
Modified Bouma Equation

- Original equation

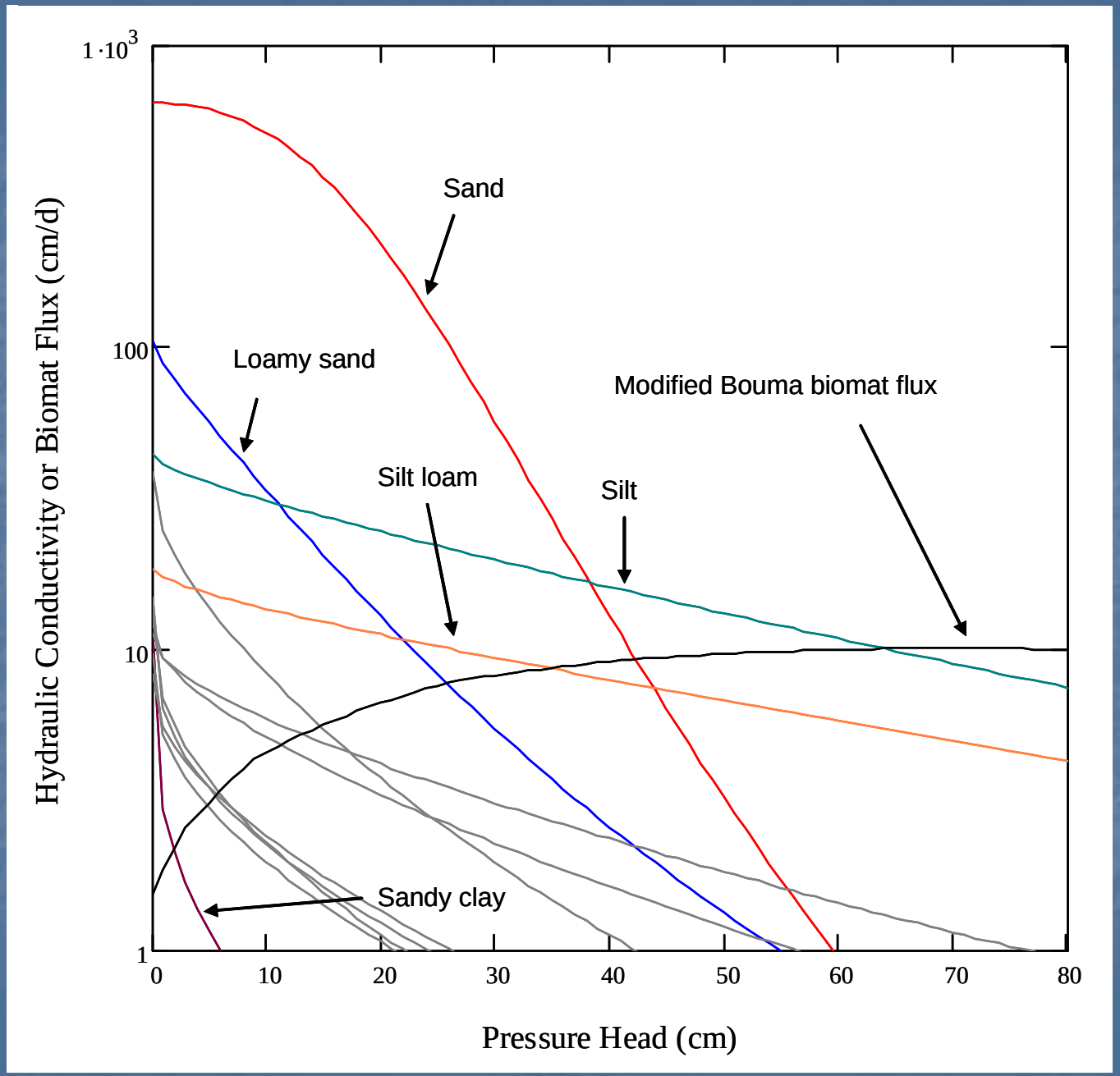
$$K_{bs}\frac{h_0 - h_s + Z_b}{Z_b} = K(h_s)$$

- Modified equation

$$\frac{Z_b}{\sum_{i=0}^{k}\frac{\frac{Z_b}{k+1}}{K_b\left[\frac{h_s - h_0}{Z_b^{\,2}}\cdot\left(\frac{Z_b}{k+1}\cdot i\right)^2 + h_0\right]}}\frac{h_0 - h_s + Z_b}{Z_b} = K(h_s)$$


Deep water table
y = 1.089x - 0.2718
R2 = 0.9583
Modified Bouma bottom flux (cm/d)
HYDRUS bottom flux (cm/d)
0
2
4
6
8
10
12
14
16
18
20

Soil textural class	Modified Bouma Equation	
	Bottom flux	Bottom flux / K_s
	cm d^{-1}	%
Sand	10.31	2
Loamy sand	8.88	8
Silt	10.80	25
Sandy loam	6.62	17
Silt loam	9.41	52
Clay	4.04	27
Sandy clay loam	4.16	32
Loam	5.59	46
Sandy clay	2.97	26
Silty clay loam	5.93	53
Silty clay	3.82	40
Clay loam	4.00	49


1·10^3
100
10
1
0
10
20
30
40
50
60
70
80
Hydraulic Conductivity or Biomat Flux (cm/d)
Pressure Head (cm)
Sand
Loamy sand
Modified Bouma biomat flux
Silt loam
Silt
Sandy clay

Soil textural class	HLR_D		Class
	cm/day	gpd/ft^2	
Silt	5.40	1.32	I
Sand	5.16	1.26	I
Silt loam	4.71	1.15	I
Loamy sand	4.44	1.09	I
Sandy loam	3.31	0.81	II
Silty clay loam	2.97	0.73	II
Loam	2.79	0.68	II
Sandy clay loam	2.08	0.51	III
Clay loam	2.00	0.49	III
Clay	2.02	0.49	III
Silty clay	1.91	0.47	III
Sandy clay	1.48	0.36	IV

HLR_D gpd/ft^2

System	Class I	Class II	Class III	Class IV
Siegrist (2007)	1.00	0.5	0.25	
Lindbo et al. (2007)	1.00	0.7	0.45	0.25
Our analysis	1.09-1.36	0.68-0.81	0.47-0.51	0.36

Soil Groupings

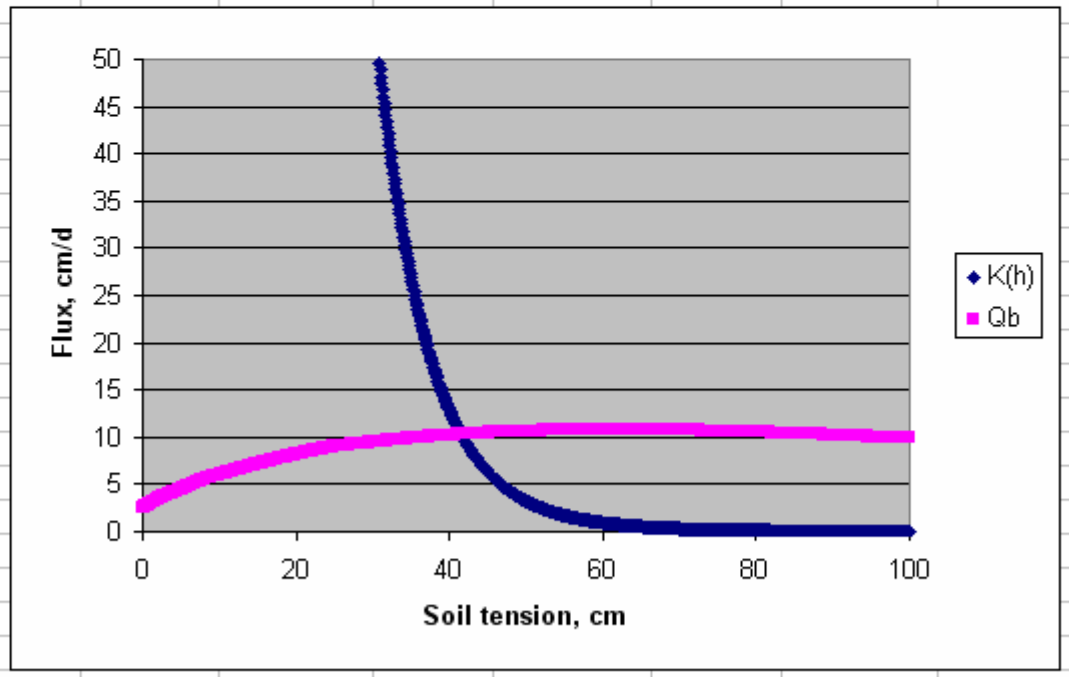
System	Class I	Class II	Class III	Class IV
Siegrit (2007)	Sand Loamy sand	Sandy loam Loam Silt loam	Silty clay loam Clay loam	
Lindbo et al. (2007)	Sand Loamy sand	Sandy loam Loam	Silt loam Clay loam Sandy clay loam Silty clay loam Silt	Sandy clay Silty clay Clay
Our analysis	Sand <u>Silt</u> <u>Silt loam</u> Loamy sand	Sandy loam <u>Silty clay loam</u> Loam	Sandy clay loam Clay loam <u>Clay</u> <u>Silty clay</u>	Sandy clay

Microsoft Excel - Bouma Calculator Spreadsheet

File Edit View Insert Format Tools Data Window Help Adobe PDF

A11 0

	A	B	C	D	E	F	G	H	I	J	K
1	**Spreadsheet for calculating bottom flux using modified Bouma equation**							22-Jan-07			
2		**User input values**									
3	**Soil**	**Theta-r**	**Theta-s**	**Alpha**	**n**	**Ks (cm/d)**	**h0 (cm)**	**Kbs (cm/d)**	**Zb (cm)**	**m**	
4	Sand	0.0530	0.3747	0.0353	3.1798	642.98	5	0.230	0.50	0.6855	
5											
6	Choose the trial value of tension from the cross-over point on curves and adjust to make the residual zero										
7	If the residual is negative you need to decrease the trial value, if it's positive you need to increase the trial value										
8	Steady flux through trench bottom in cm/d is given in the box below										
9											
10	**Trial Value**										
11	0										
12											
13	**Residual**										
14	640.45										
15											
16	**Flux =**	2.53	cm/day								
17		0.62	gpd/ft^2								



Calculator / Soil textural classes / Locked worksheet

Ready NUM

Microsoft Excel - Bouma Calculator Spreadsheet

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A11 40

	A	B	C	D	E	F	G	H	I	J	K
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2		**User input values**									
3	**Soil**	**Theta-r**	**Theta-s**	**Alpha**	**n**	**Ks (cm/d)**	**h0 (cm)**	**Kbs (cm/d)**	**Zb (cm)**	**m**	
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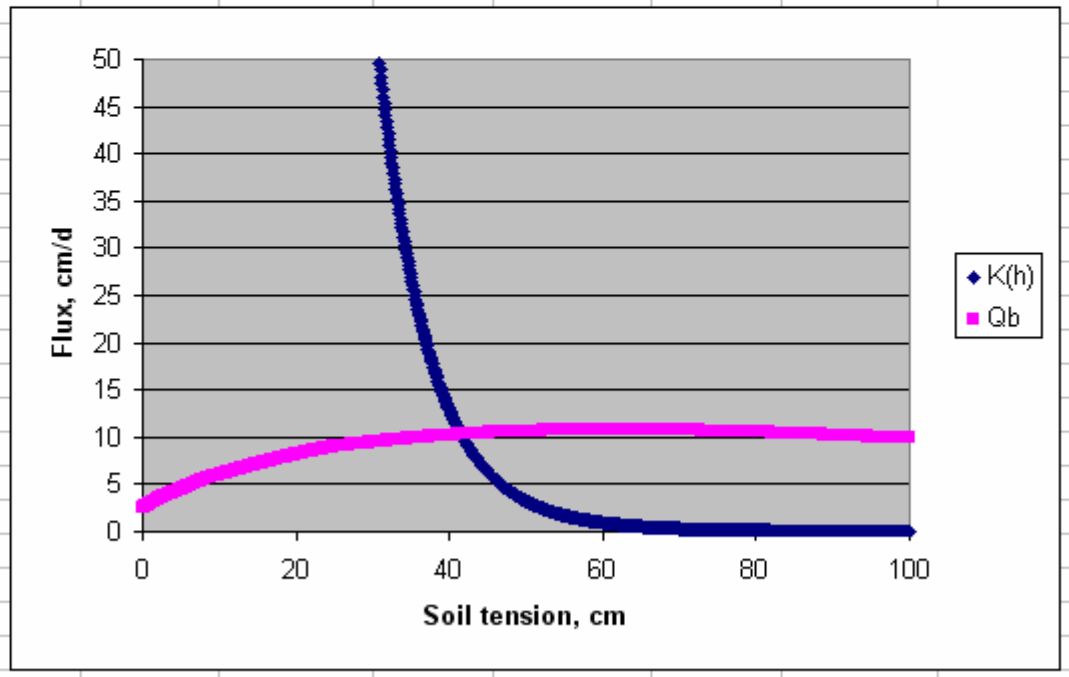
5											
6	Choose the trial value of tension from the cross-over point on curves and adjust to make the residual zero										
7	If the residual is negative you need to decrease the trial value, if it's positive you need to increase the trial value										
8	Steady flux through trench bottom in cm/d is given in the box below										
9											
10	**Trial Value**										
11	40										
12											
13	**Residual**										
14	2.62										
15											
16	**Flux =**	10.23	cm/day								
17		2.51	gpd/ft^2								



Calculator / Soil textural classes / Locked worksheet

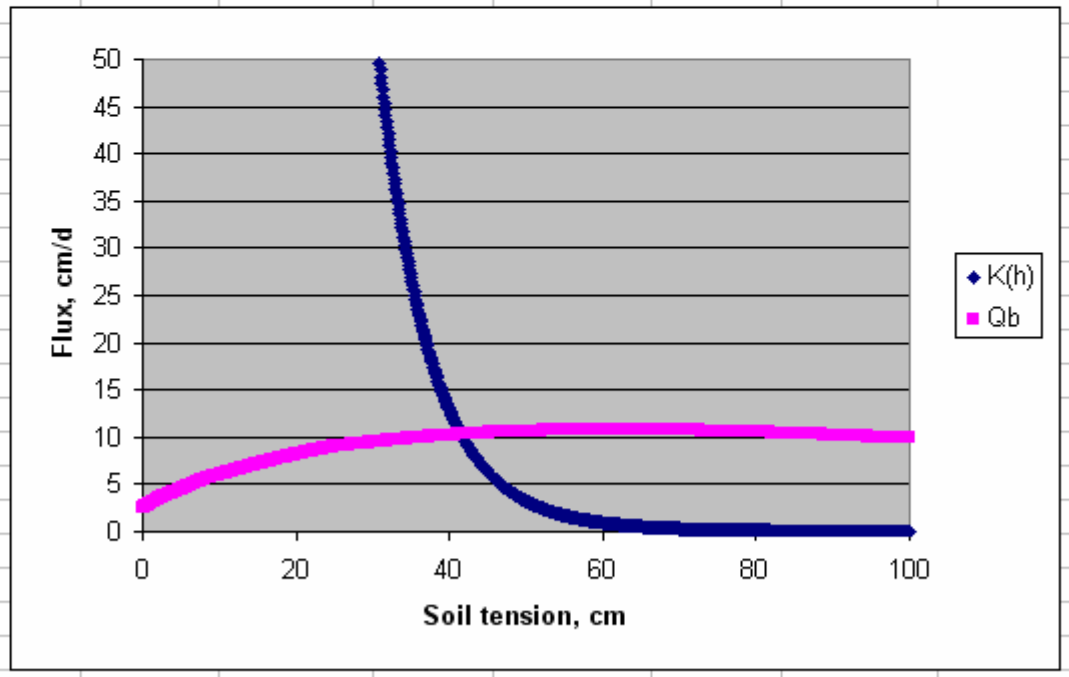
Ready NUM

Microsoft Excel - Bouma Calculator Spreadsheet

File Edit View Insert Format Tools Data Window Help Adobe PDF

A11 41

	A	B	C	D	E	F	G	H	I	J	K
1	**Spreadsheet for calculating bottom flux using modified Bouma equation**							22-Jan-07			
2		**User input values**									
3	**Soil**	**Theta-r**	**Theta-s**	**Alpha**	**n**	**Ks (cm/d)**	**h0 (cm)**	**Kbs (cm/d)**	**Zb (cm)**	**m**	
4	Sand	0.0530	0.3747	0.0353	3.1798	642.98	5	0.230	0.50	0.6855	
5											
6	Choose the trial value of tension from the cross-over point on curves and adjust to make the residual zero										
7	If the residual is negative you need to decrease the trial value, if it's positive you need to increase the trial value										
8	Steady flux through trench bottom in cm/d is given in the box below										
9											
10	**Trial Value**										
11	41										
12											
13	**Residual**										
14	0.83										
15											
16	**Flux =**	10.28	cm/day								
17		2.52	gpd/ft^2								



Calculator / Soil textural classes / Locked worksheet

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Microsoft Excel - Bouma Calculator Spreadsheet

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A11 41.52

	A	B	C	D	E	F	G	H	I	J	K
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2		**User input values**									
3	**Soil**	**Theta-r**	**Theta-s**	**Alpha**	**n**	**Ks (cm/d)**	**h0 (cm)**	**Kbs (cm/d)**	**Zb (cm)**	**m**	
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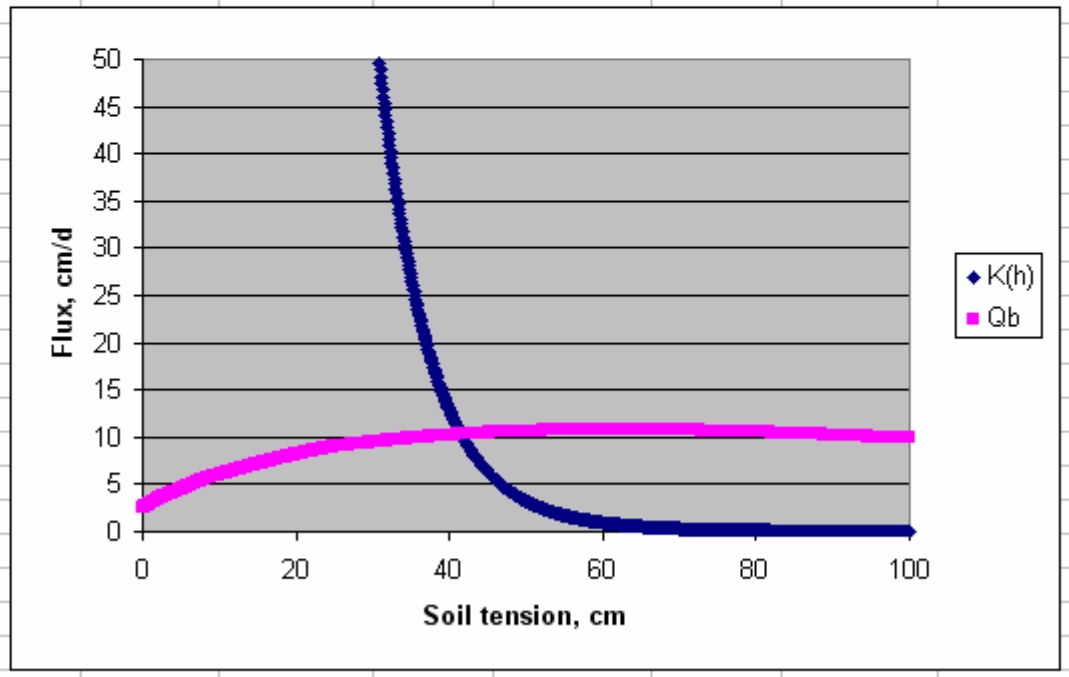
5											
6	Choose the trial value of tension from the cross-over point on curves and adjust to make the residual zero										
7	If the residual is negative you need to decrease the trial value, if it's positive you need to increase the trial value										
8	Steady flux through trench bottom in cm/d is given in the box below										
9											
10	**Trial Value**										
11	41.52										
12											
13	**Residual**										
14	0.00										
15											
16	**Flux =**	10.31	cm/day								
17		2.53	gpd/ft^2								



Calculator / Soil textural classes / Locked worksheet

Ready NUM

Conclusions

- Modified Bouma equation can be used to develop HLR_D for OWSs
  - Based entirely on soil and biomat hydraulic properties
- Not recommending a particular set of HLR_D but rather a <u>process</u>
  - Users can make many choices to tailor system to their needs
  - Ponding depth, biomat thickness, biomat conductivity, safety factor, soil groupings, etc.
- Unsaturated soil and biomat properties are important
- Bouma Calculator spreadsheet available at
  - www. cropsoil.uga.edu/soilphysics/publications.html