UNIVERSITY OF WATERLOO

Environmental Modelling & Analysis Group

IP3, 7-10September, 2011, Saskatoon, Saskatchewan, Canada

Improved Processes & Parameterisation for Prediction in Cold Regions

Progress in Closing the Water Balance with Land Surface Schemes

E.D. Soulis, J.R. Craig, and G. Liu

Process

- Lateral flow is an important process for part of the water cycle, yet it is the most poorly parameterised.
  - It is often completely ignored, all flow is vertical and lateral flow is from the saturated zone or;
  - assumed to be some simple decay function of storage with no explicit reference to resistance or;
  - modelled using expensive numerical solutions to Richard's Equation

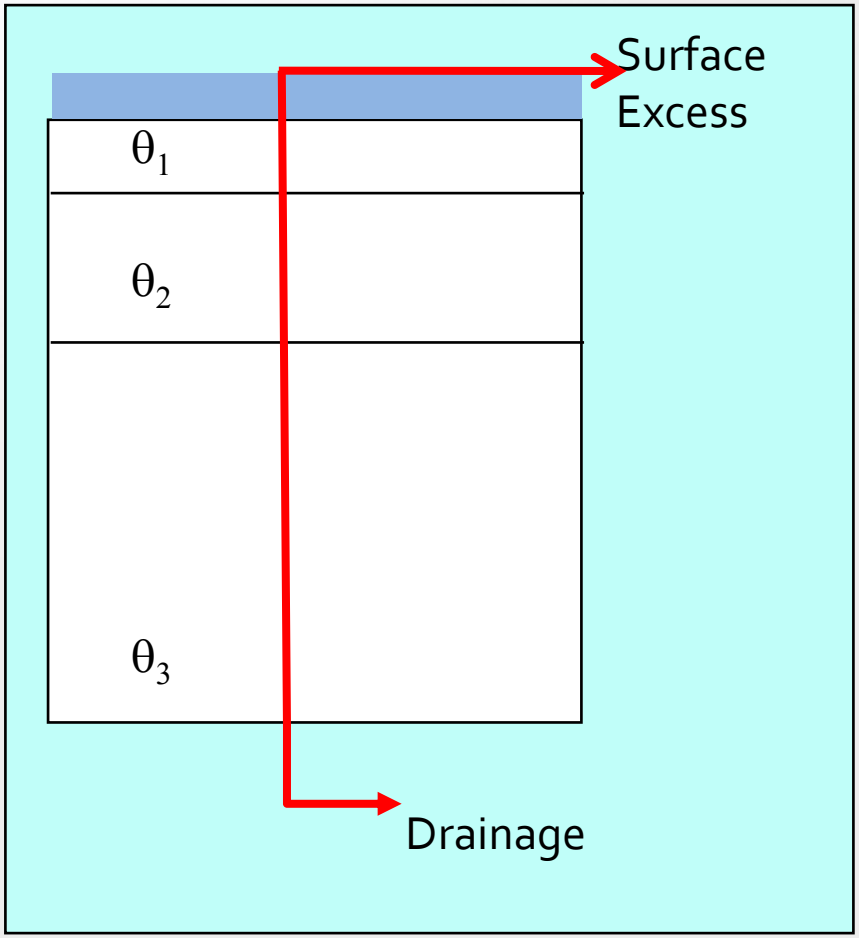
Approach

- Find analytical approximation to bridge gap between Richard's Equation and $Q=Q_0 S_{eff}^D$, where Q_0 is maximum interflow, S_{eff} is effective saturation given by $(S-S_R)/(S_C-S_R)$
- Q_0 is predictable from Darcy's equation for saturated flow
- S_{eff} is based on retained soil moisture (field capacity)
- D is an exponent >1

Parameterisation

- Needed to establish configuration of subsurface system
- Started with 3 layer FlatCLASS system (circa 1990), currently using 6 layer, sloped WATDRAIN2
- WATDRAIN3 being tested

Classic, Flat CLASS



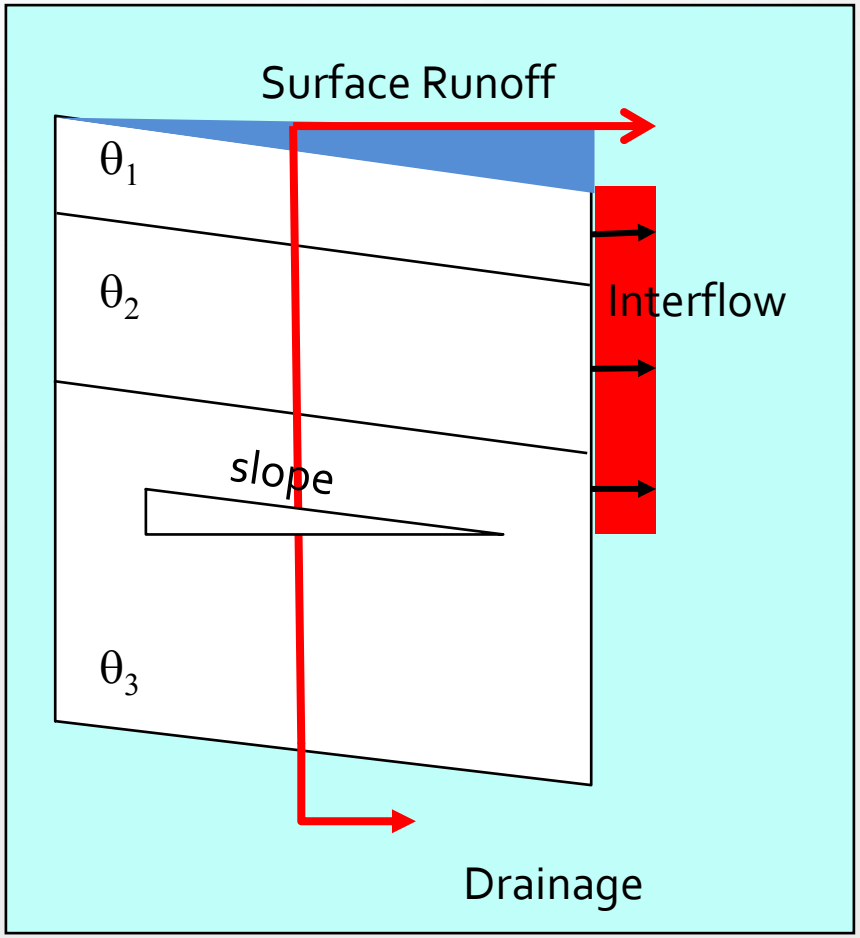
Features

- Simple
- Good for vertical fluxes over large areas

Problems

- Poor timing of run-off
- Local distribution of soil moisture is not represented

Slope CLASS/WATDRAIN-O



Manning's Equation

$$Q_{over} = \left(\frac{1}{n}\right) \cdot d_e^{\,5/3} \cdot \Lambda_I^{\,1/2} \cdot L_v$$

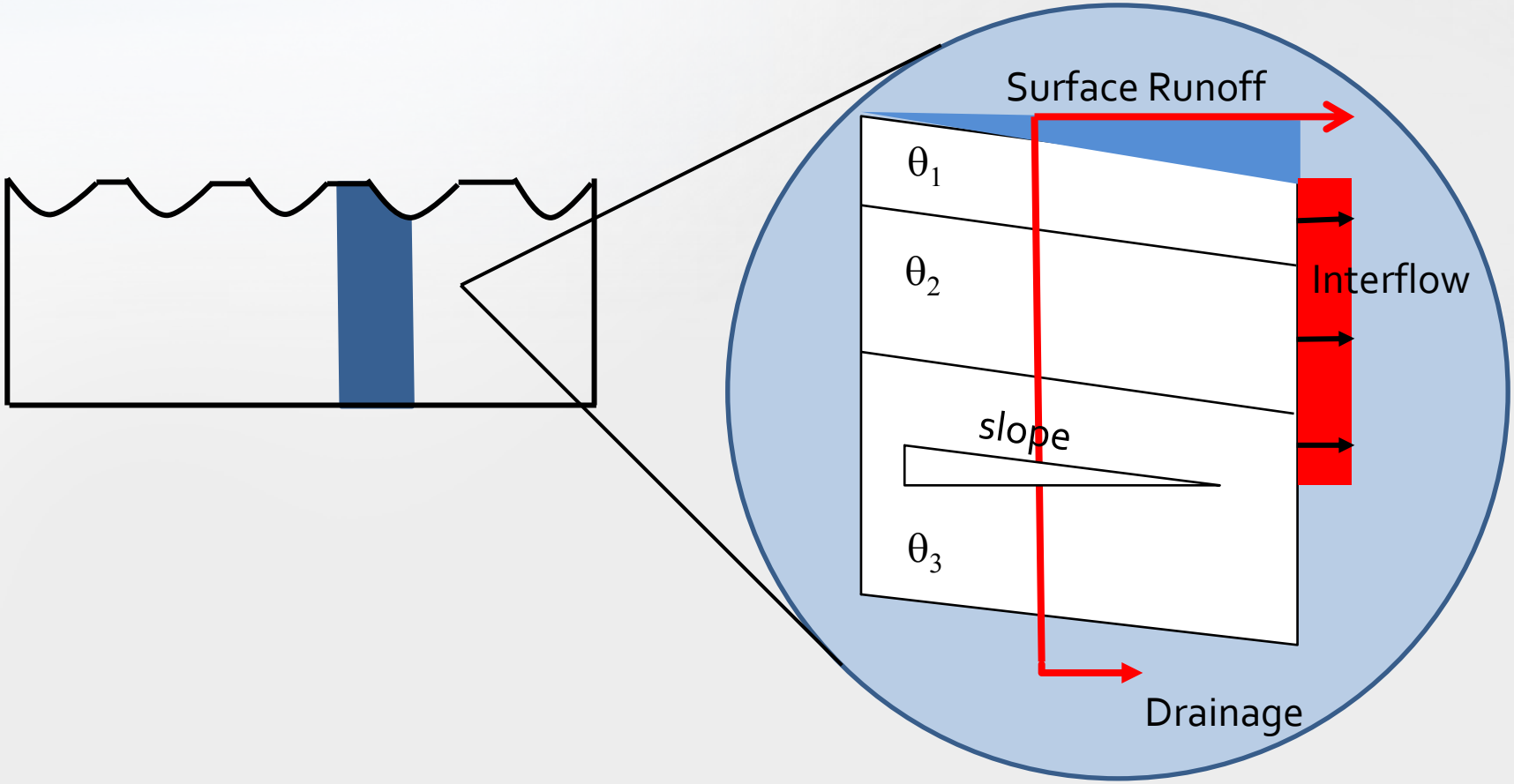
Richard's Equation

$$-\frac{\partial K_v(\theta)}{\partial z} + \frac{\partial}{\partial z}\left[K_v(\theta)\frac{\partial \psi(\theta)}{\partial z}\right] = \frac{\partial \theta}{\partial t}$$

Darcy's Law

$$q_{drain} = K_v(\theta_3)$$

"Groovy" CLASS



Features

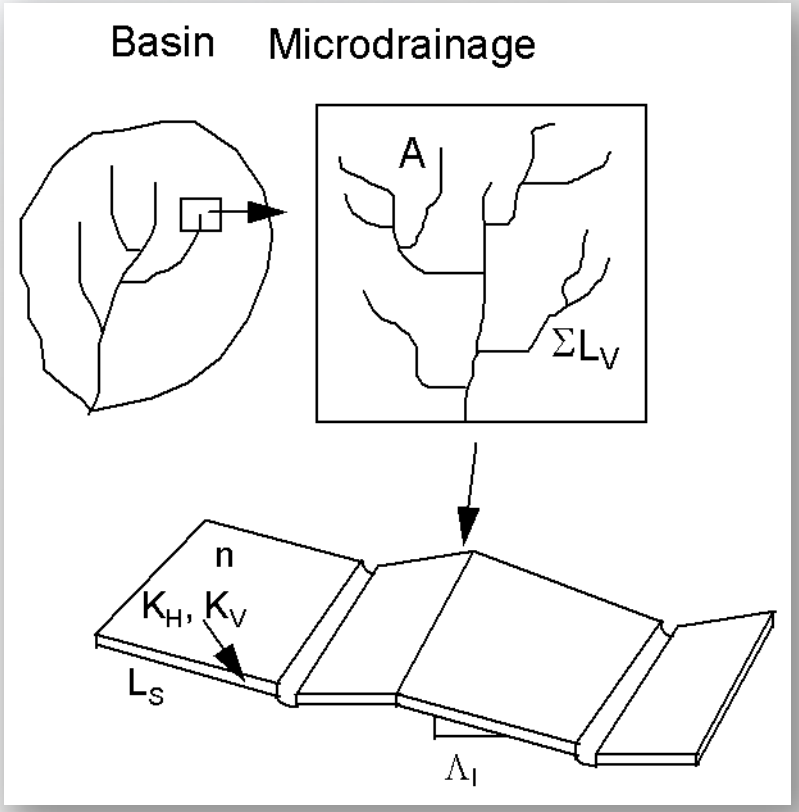
- Physically based
- Sensitive to soil moisture

Problems

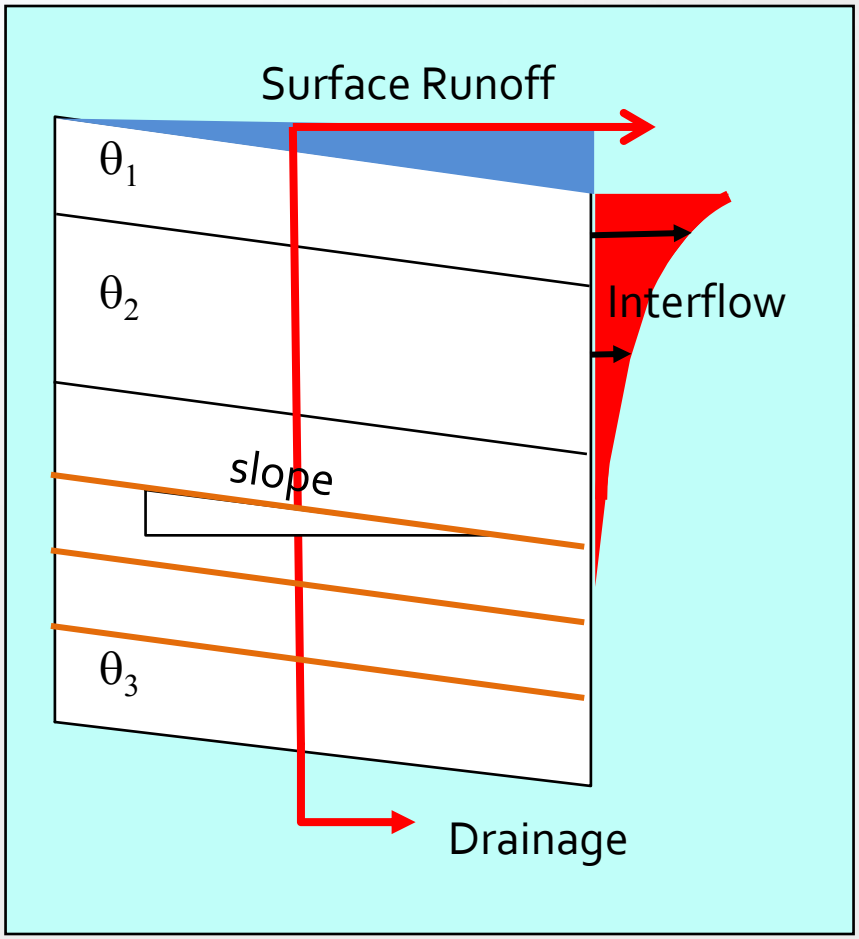
- Dried soil completely under drought conditions
- Too flashy and recession curves too steep
- Difficult to calibrate

Souils and Snelgrove, 2000

Subgrid Representation



WATDRAIN1



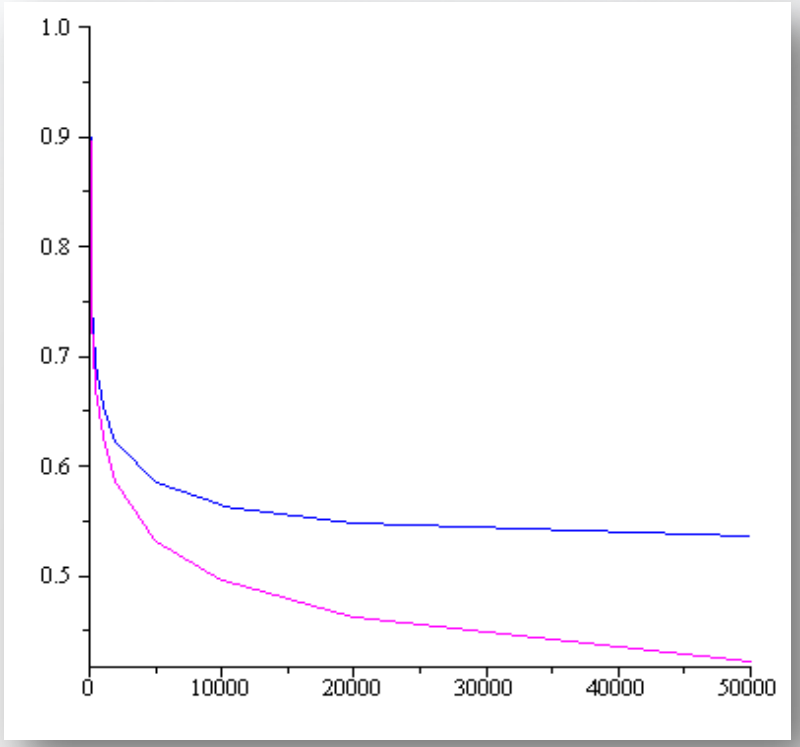
Features

- Easier to calibrate and more realistic hydrographs
- Uses same horizontal and vertical flow layers

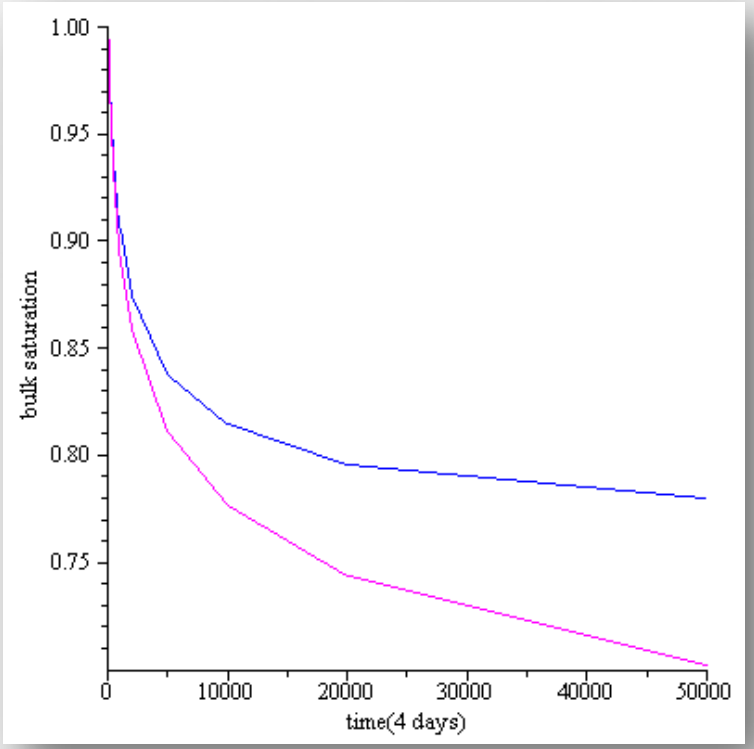
Problems

- No soil suction (still allows soil to dry out completely)

Bulk Saturation



sand

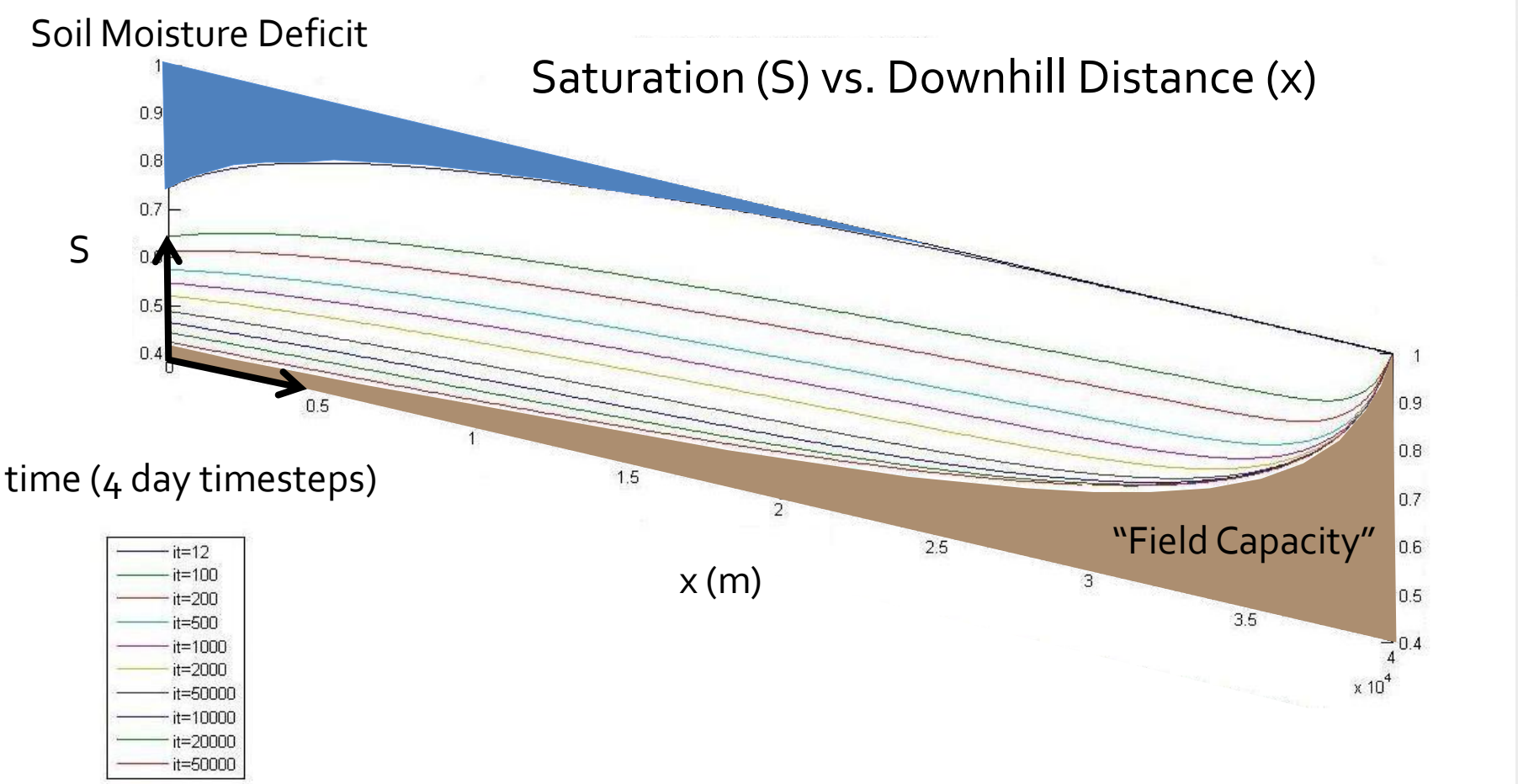


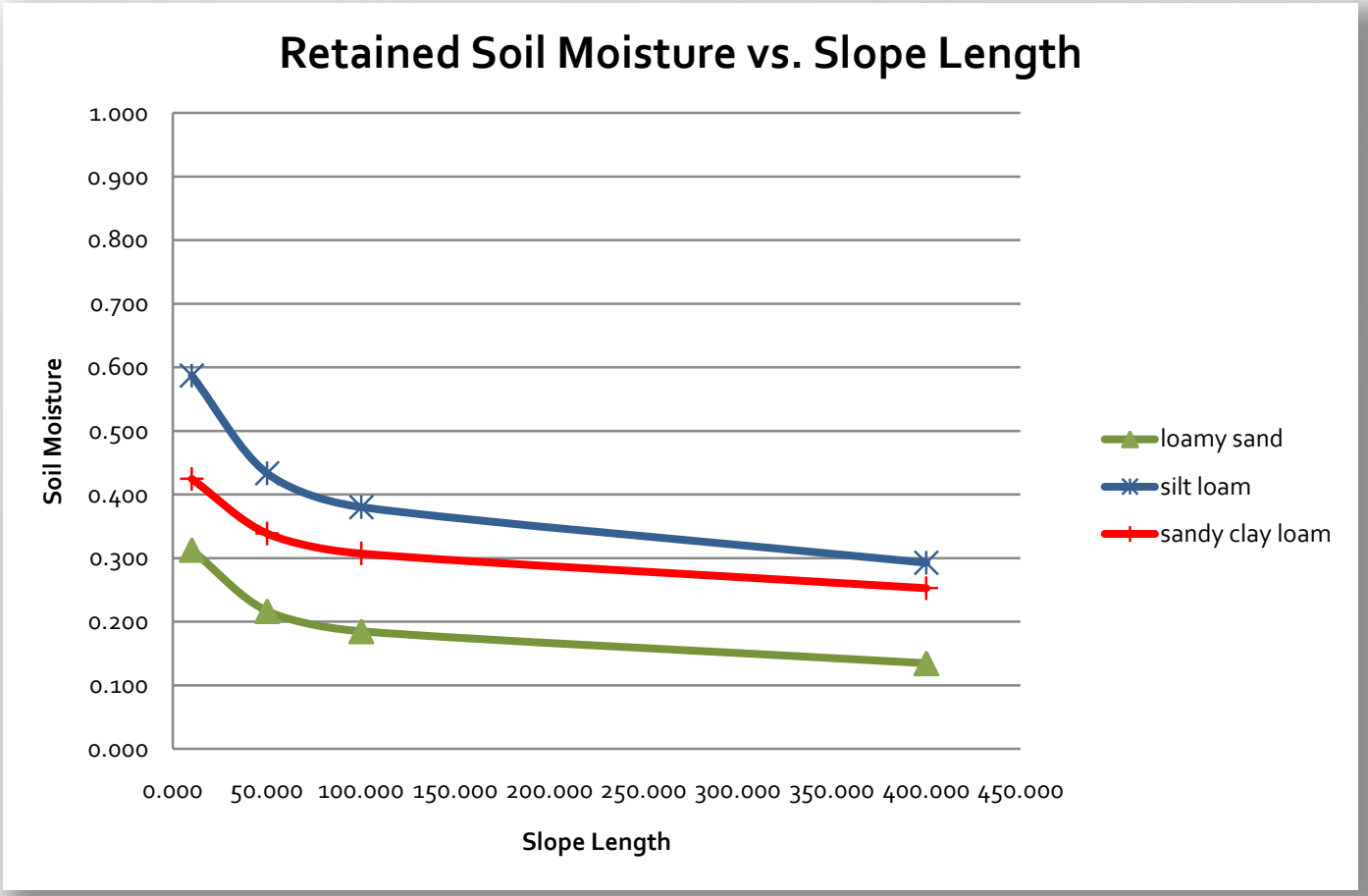
silt

Process Round 2 (Back to the Drawing Board)

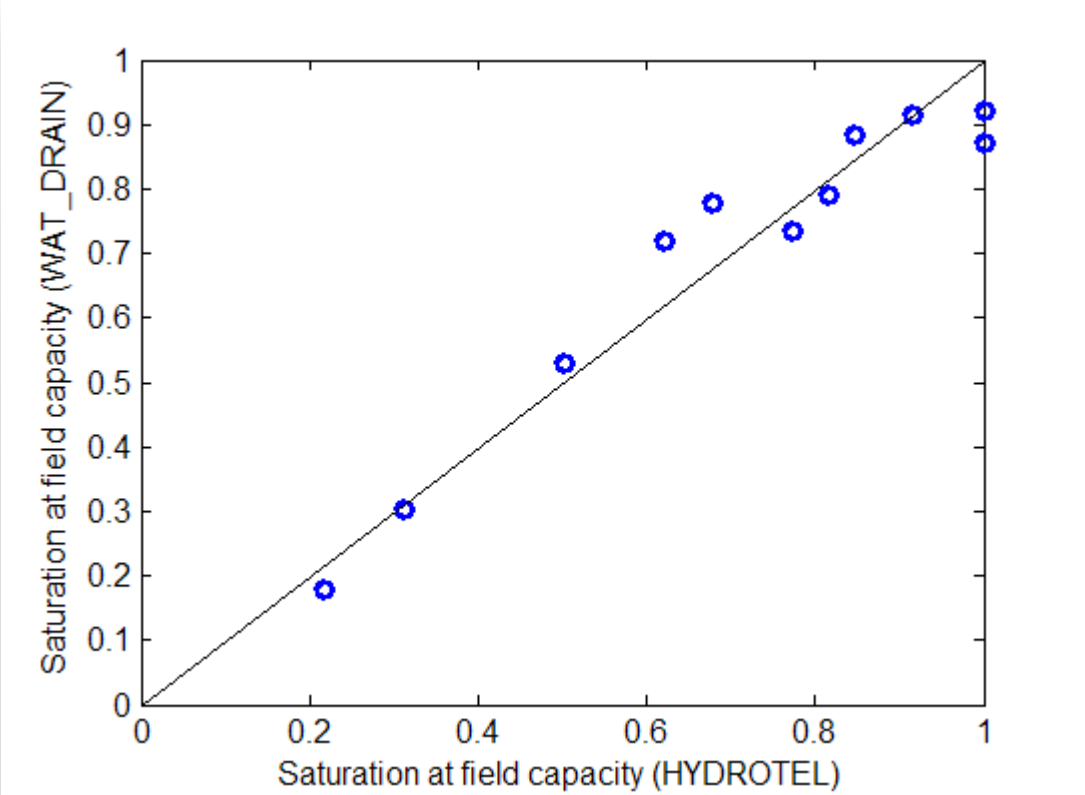
- WATDRAIN1 had worked for MAGS, but was inadequate for IP3
- Could not avoid addressing soil suction
- Used finite difference numeric solution to Richard's Equation guided search for analytic solution

Numerical Solution to Richard's Equation



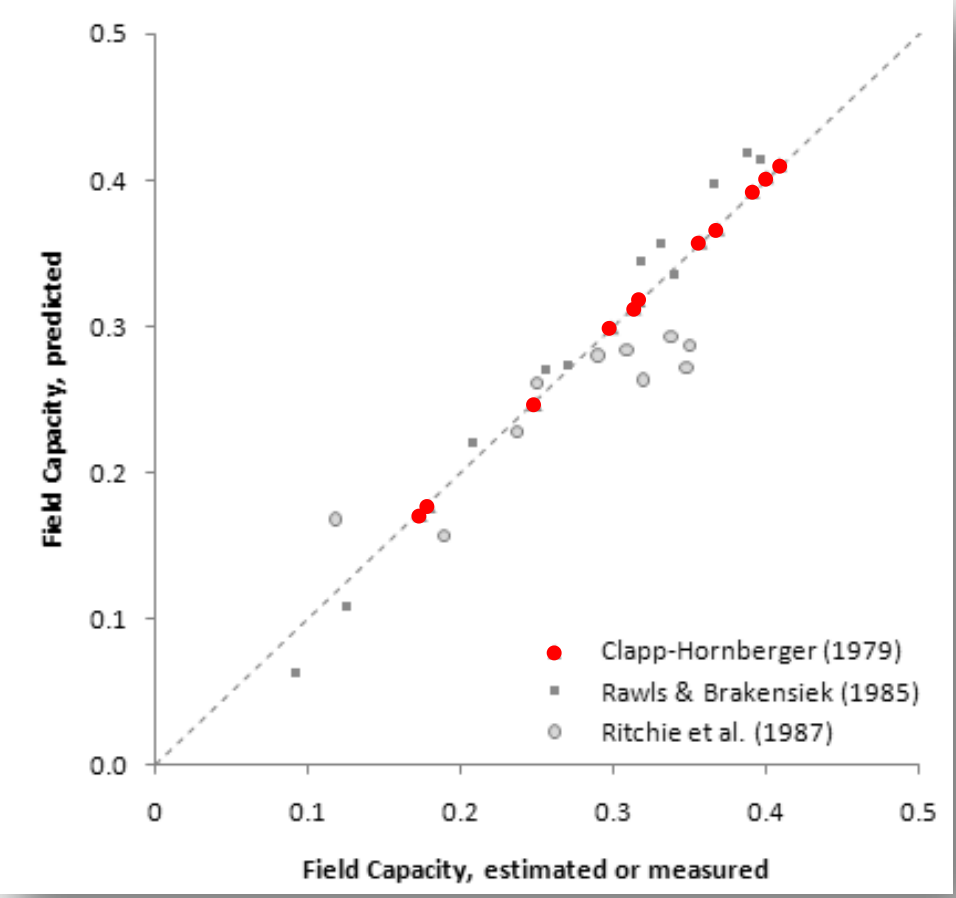

Retained Soil Moisture vs. Slope Length
Soil Moisture
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0.000
50.000
100.000
150.000
200.000
250.000
300.000
350.000
400.000
450.000
Slope Length
loamy sand
silt loam
sandy clay loam

Predicted Saturation at Field Capacity



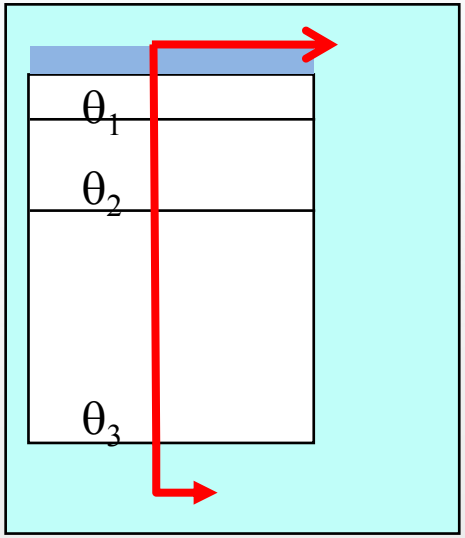
Retained soil moisture (depth of 50 cm) WATDRAIN vs. HYDROTEL

Field Capacity Comparison

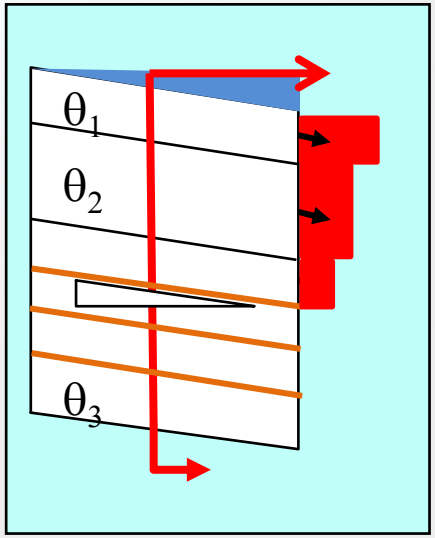


A simple expression for the bulk field capacity of a sloping soil horizon, 2010 E. D. Soulis, J. R. Craig, V. Fortin, G. Liu

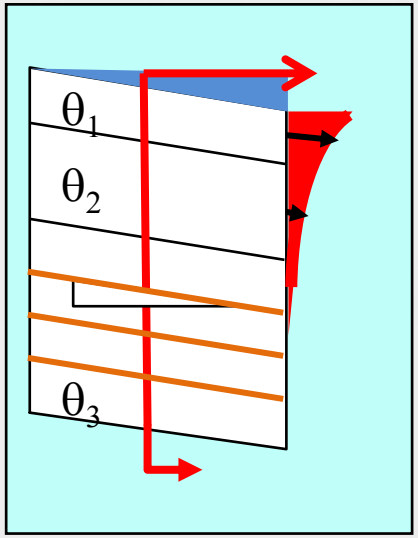
Prediction



CLASS
CCC



GEM Model
RPN



Stand Alone MESH
NHRI

Suction,ψ vs. Downhill Distance,x

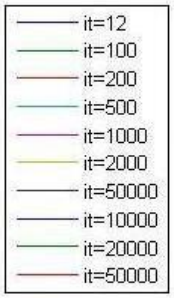
$$\psi_g = \left(\frac{x+\epsilon}{x_s+\epsilon}\right)^{\frac{-b}{2b+2}\left(1-\frac{x}{x_s}\right)^2}$$

Ψ (cm)

Ψ?

$$\psi_f = \psi_0 - \Lambda(L-x)$$

time (4 day timesteps)



X(m)

Combined Flow

- It can be argued that the hydraulic resistance is proportional to the square of suction. Therefore, using a parallel electric circuit analog:

$$\psi = -\left(\frac{w}{\psi_g^2} + \frac{1-w}{\psi_f^2}\right)^{-\frac{1}{2}}$$

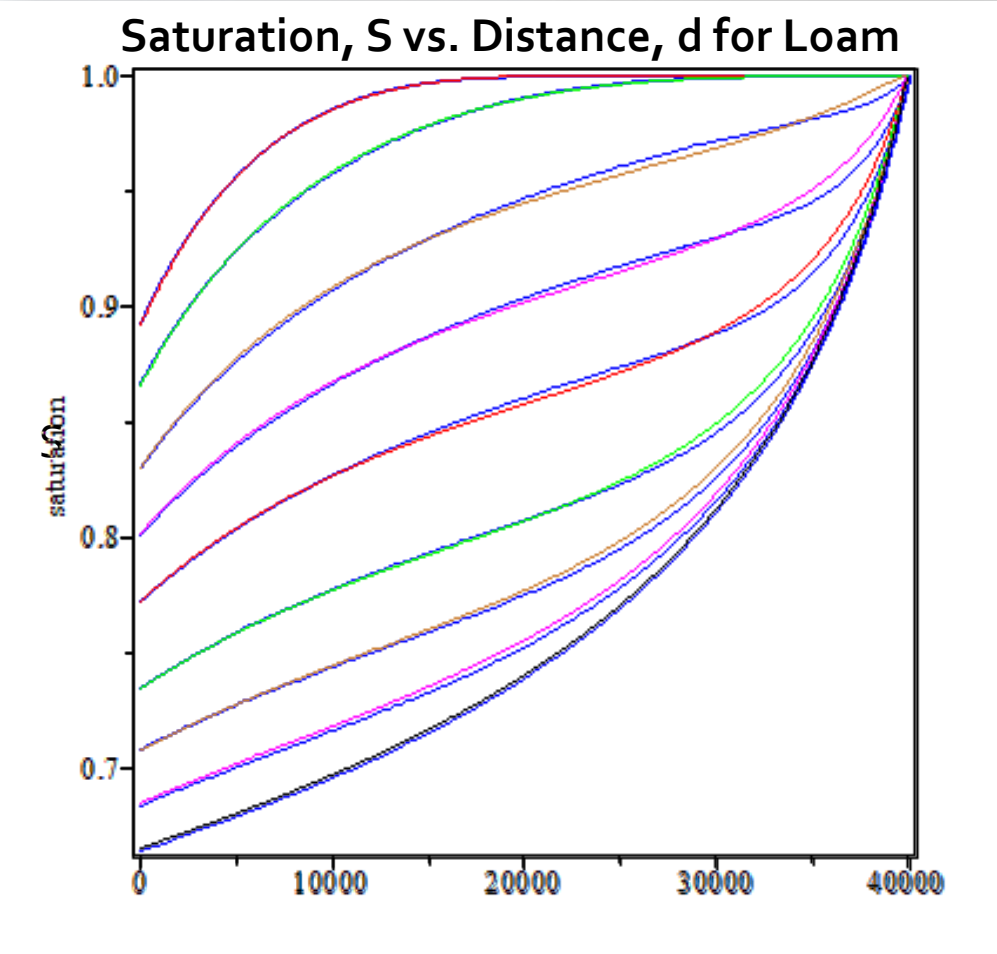
- w is a weighting factor, where:

$$w = w_a w_x + (1 - w_x)(w_Q)$$

- w_a reflects the left boundary condition
- w_Q reflects right boundary condition
- And w_x is a spatial interpolator

$$w_x = \cos\left(\frac{\pi}{4} \cdot \frac{x}{L}\right)$$

Testing Parameterisation



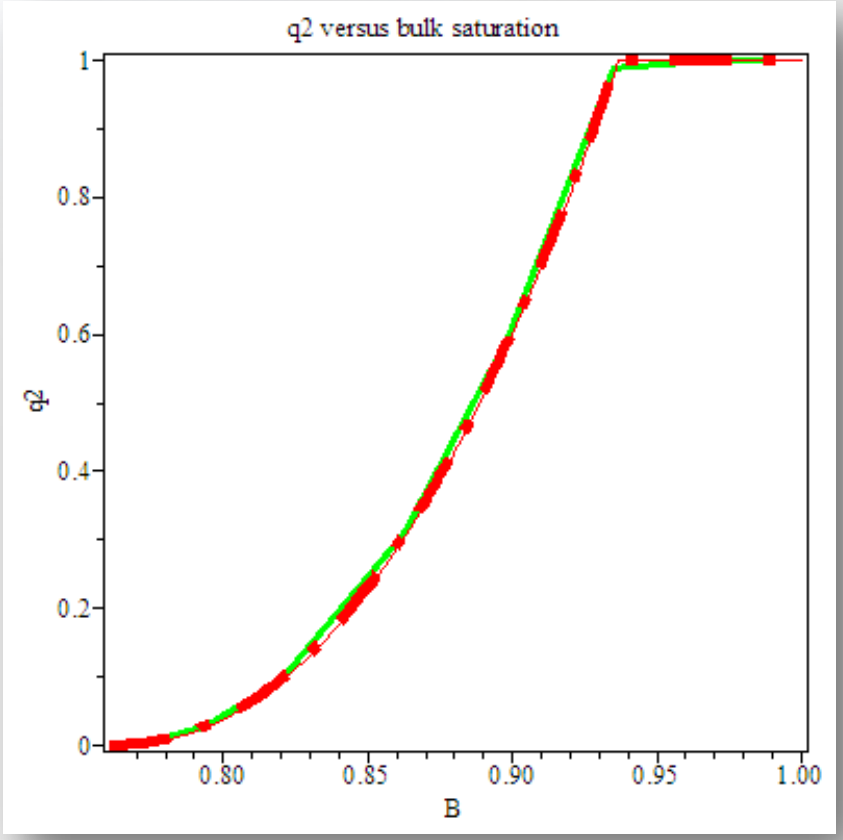
Numerical Solution

Analytical Approximation

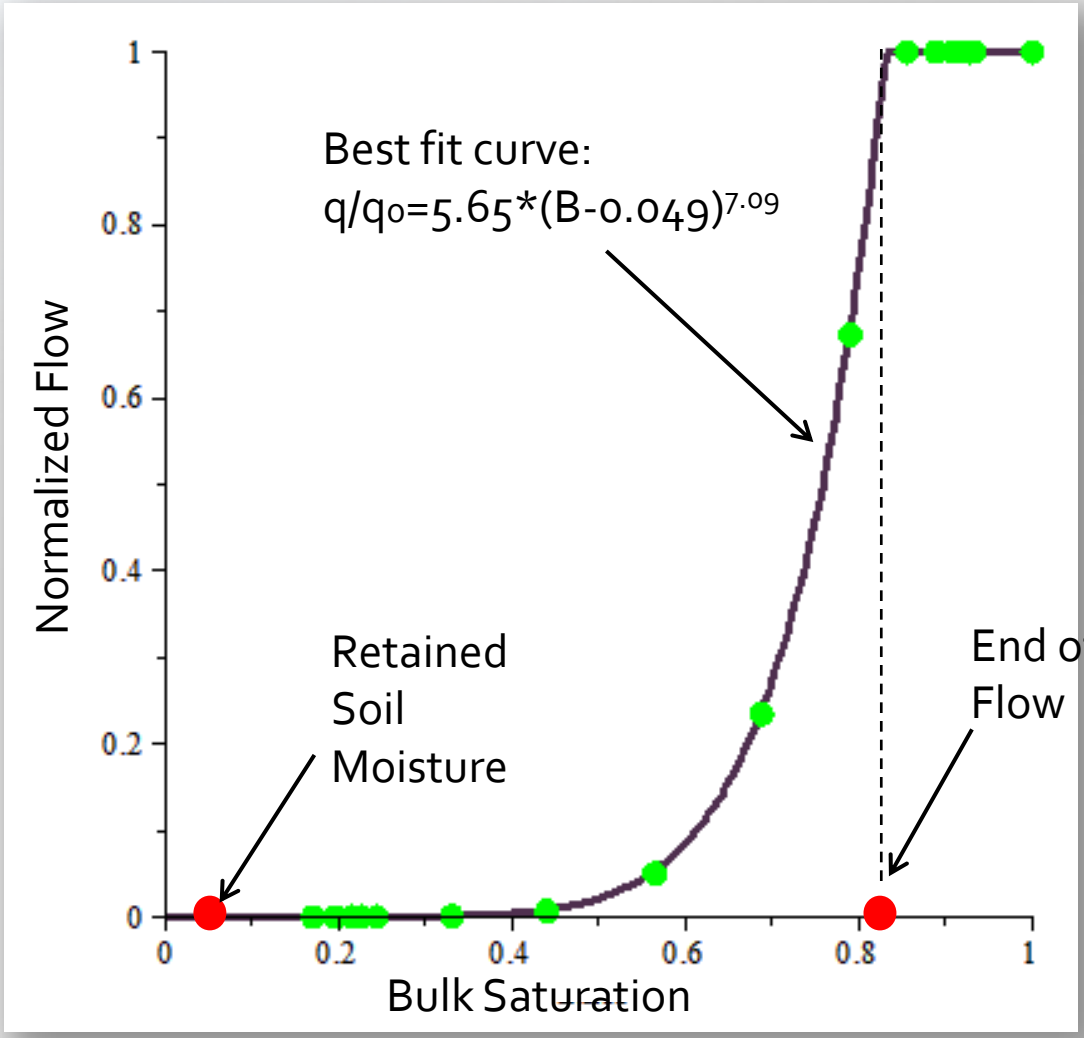
Prediction

- Soil moisture profile can be used to identify saturated area, recharge and interflow

Target Characteristic Curve

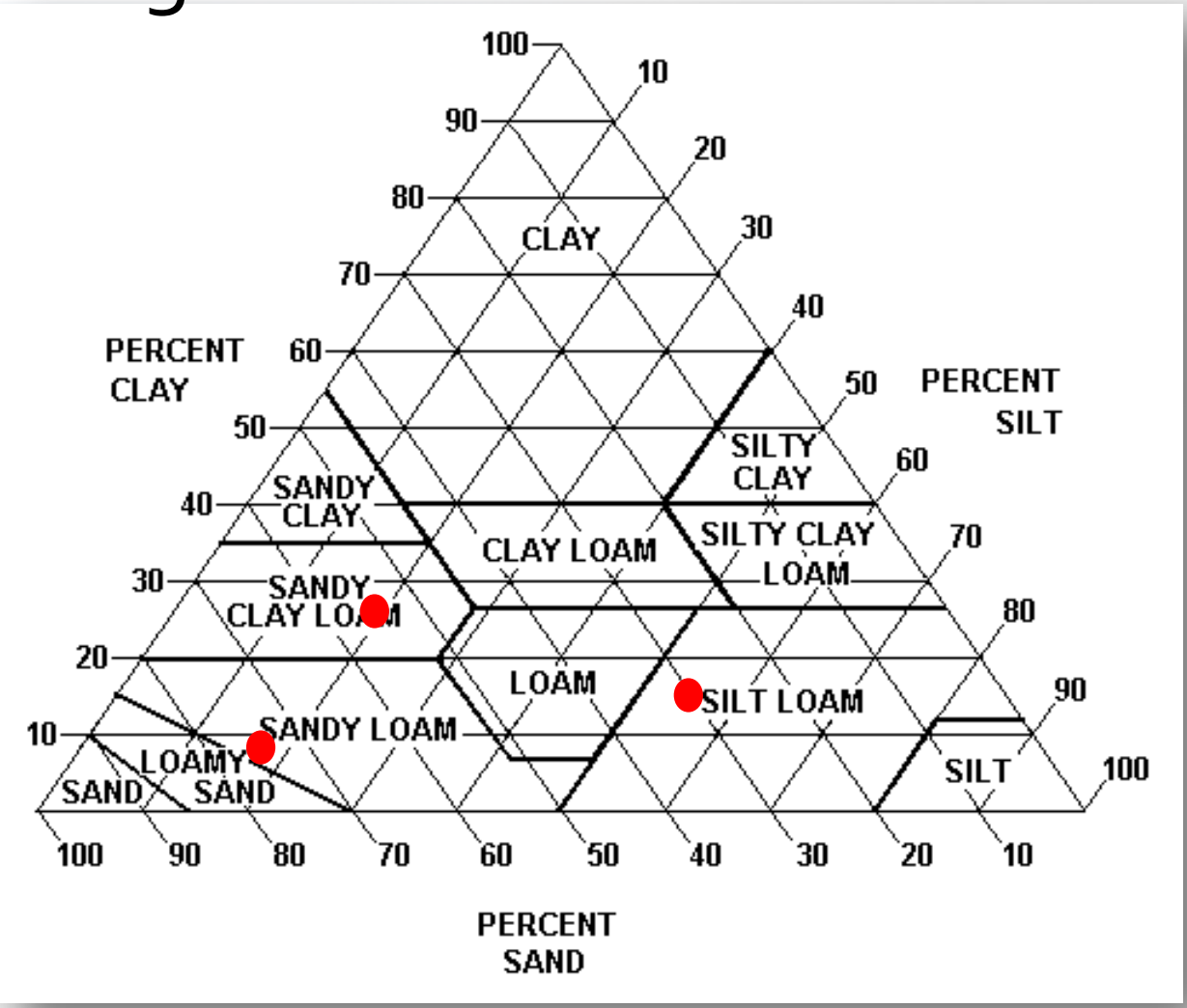


Characteristic Curve



- Solution at 20 specified timesteps

SCS Triangle

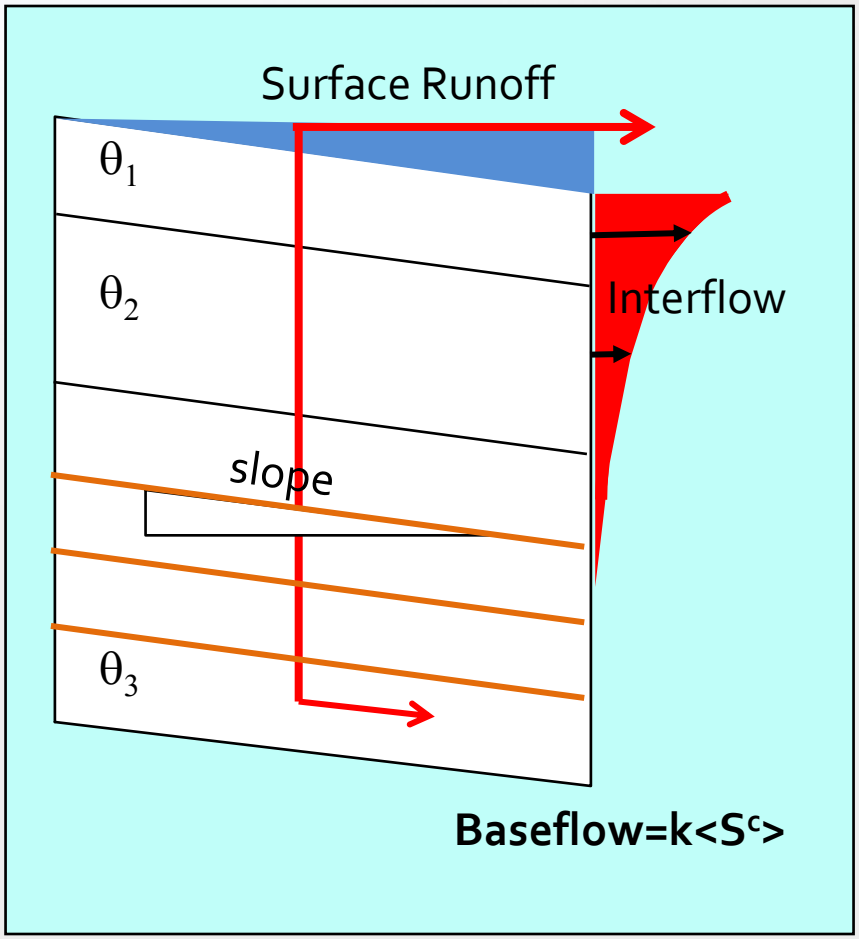


Characteristic Curve Overview

	Slope %	Slope Length	Sand (%)	Clay (%)
Sand	6%	1000m	74.6	7.17
Silt	6%	1000m	54.8	26.5
Loam	6%	1000m	30.2	15.6

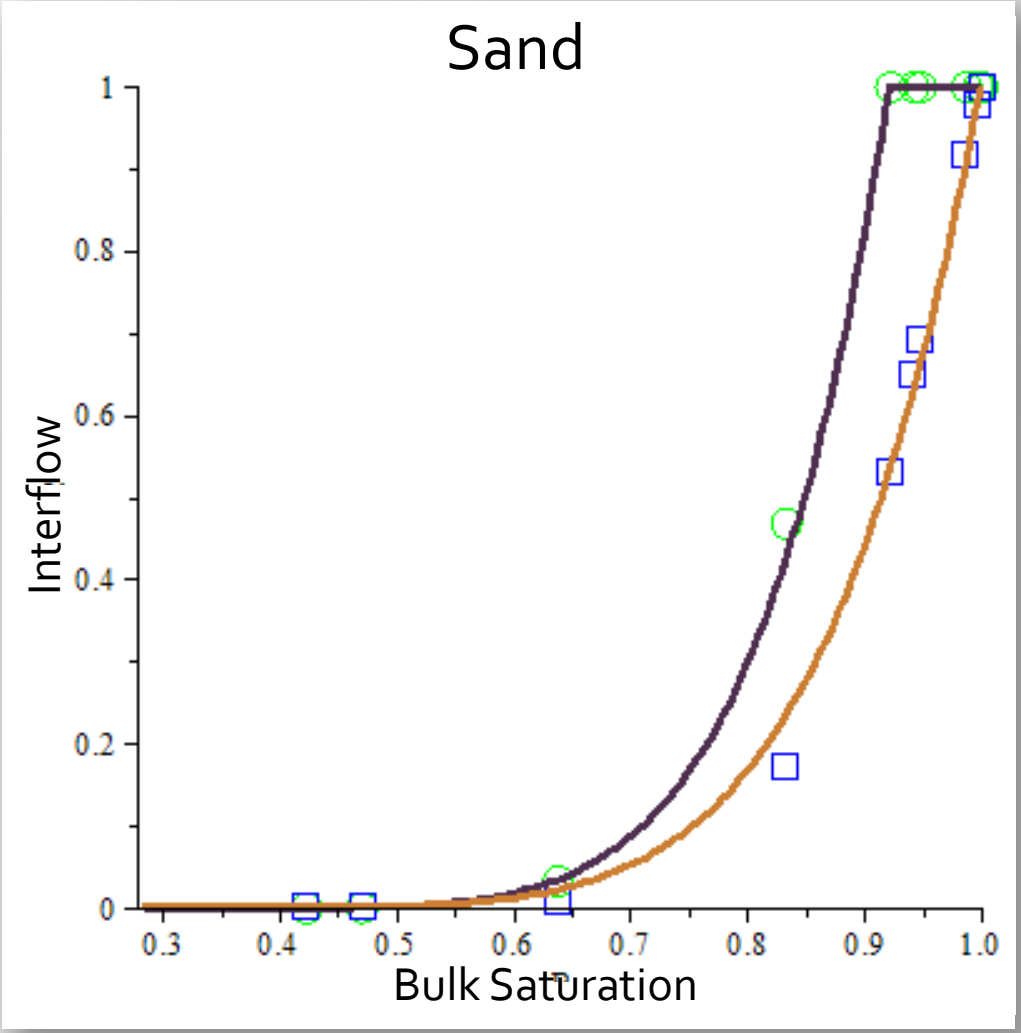
	Q_0 (m/sec)	S_R	S_C	D
Sand	1.05×10^{-5}	0.285	0.922	5.74
Silt	3.77×10^{-7}	0.549	0.949	4.94
Loam	4.16×10^{-7}	0.494	0.932	4.14

WATDRAIN3

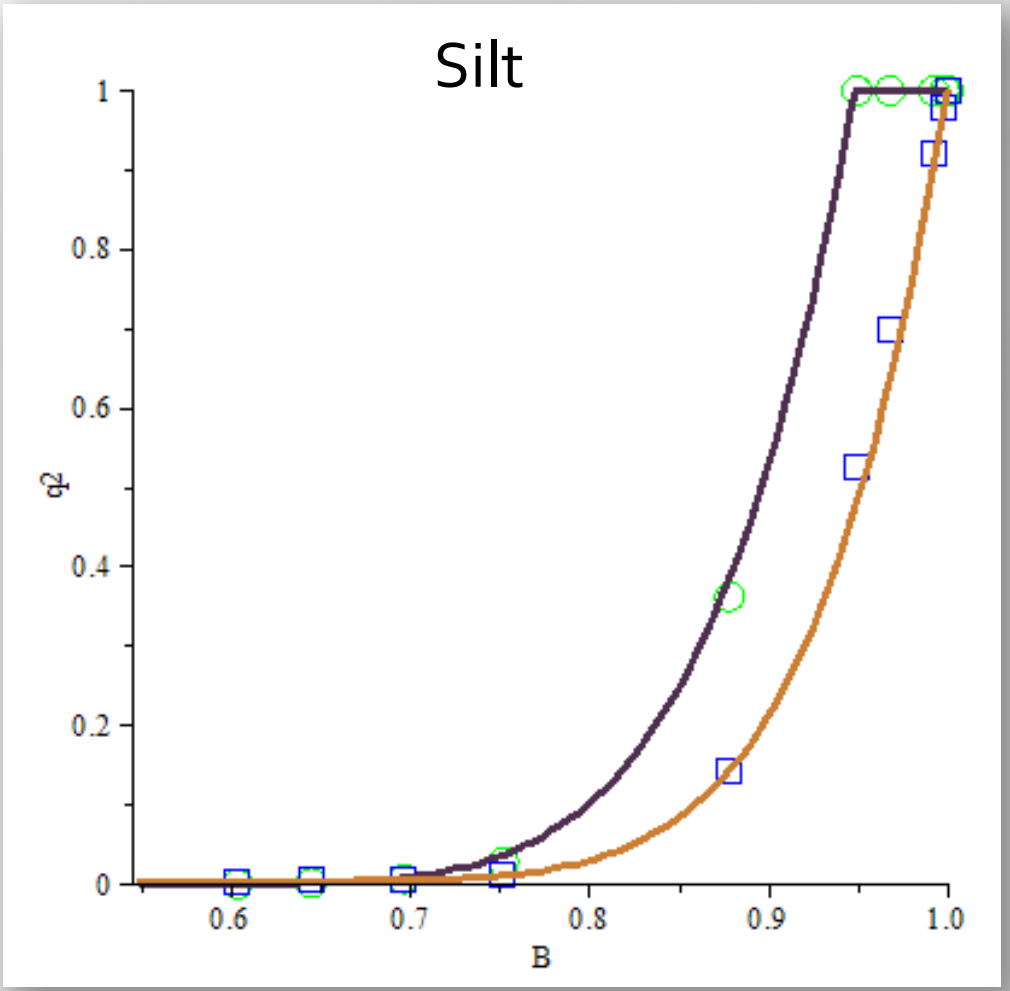


Proposed Characteristic Curve

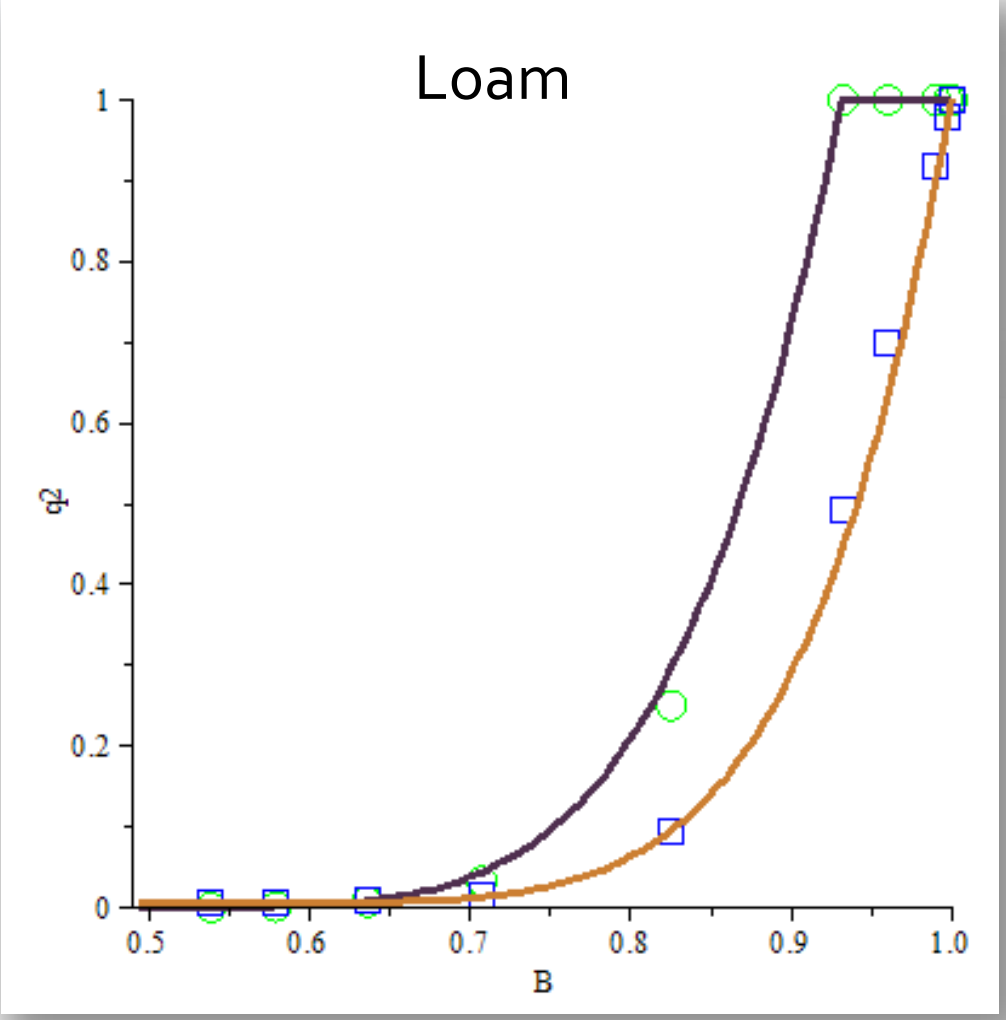
Normalized Interflow
Normalized Recharge
Solution Points



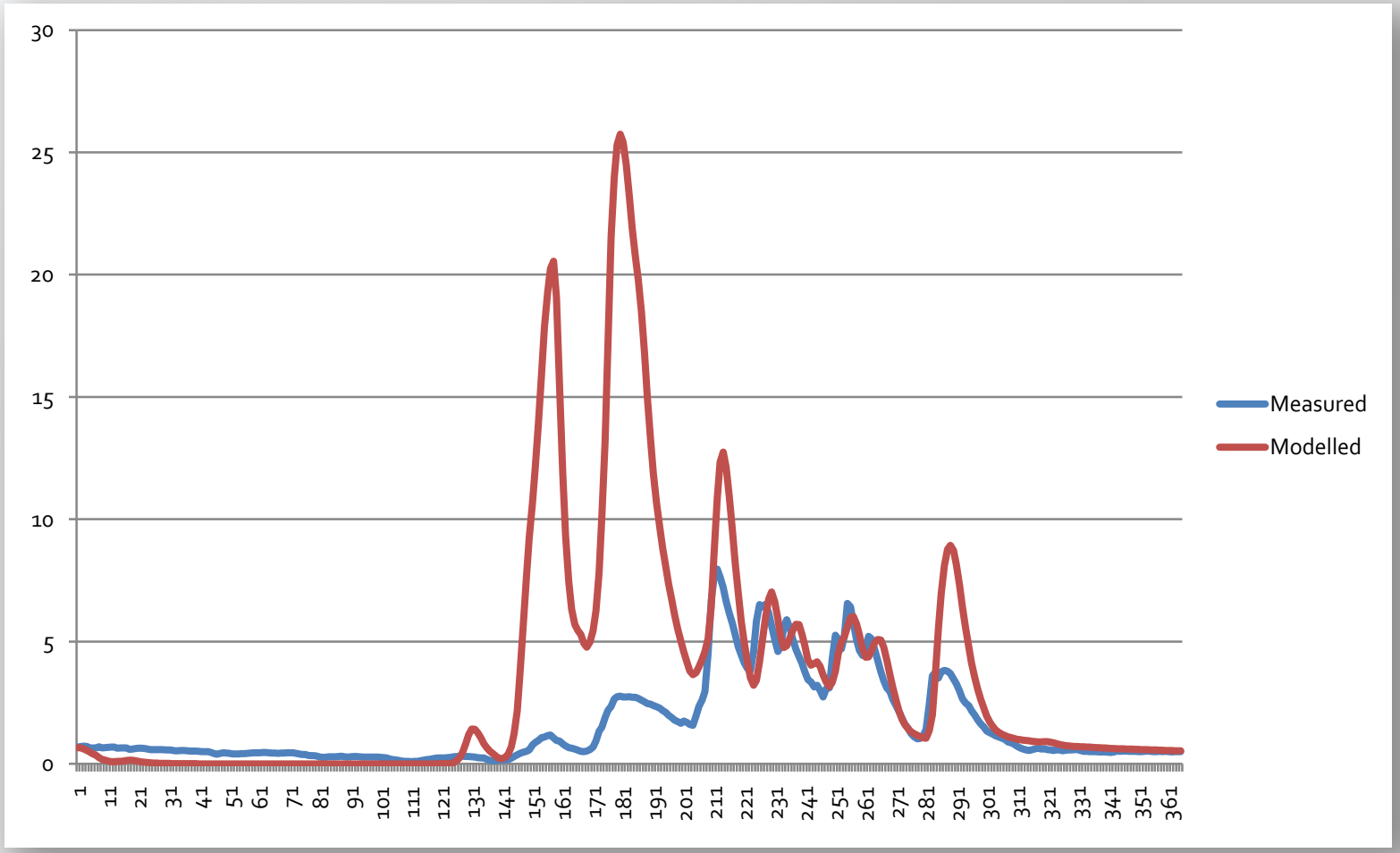
Normalized Interflow
Normalized Recharge
Solution Points



Normalized Interflow
Normalized Recharge
Solution Points



Whitegull Hydrograph



SSRB Hydrograph