The Effect of Precipitation Variability on Root Depth and the Partitioning of Hydrologic Fluxes

Andrew J. Guswa

Picker Engineering Program
Smith College

5th Annual WRRC Conference
8 March 2008

What controls root depth?

Premise

- Water is the resource that drives root depth, and roots will find and use water within the root-zone.
- Roots will respond plastically to their environment at time scales of weeks to months.
- Root depth is determined by the depth at which the marginal carbon cost of roots is equal to the marginal benefit.

Benefit and Cost of roots

Vegetation	
WUE	water-use efficiency
RLD	root-length density
ρ_r^{-1}	specific root length
γ_r	root respiration

$$B(Z_r) = WUE \cdot \langle T(Z_r) \rangle$$

$$C(Z_r) = \int_0^{Z_r} \gamma_r \cdot \rho_r \cdot RLD \cdot dz$$

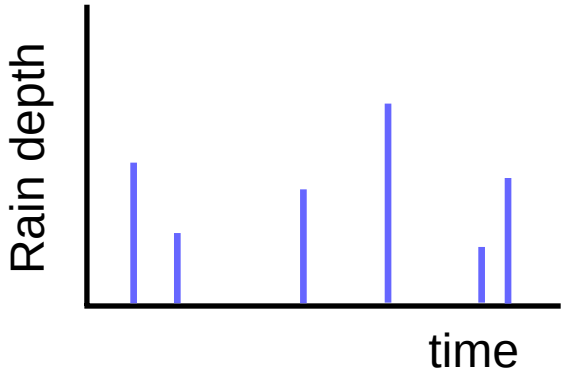
Marginal benefit equals marginal cost when

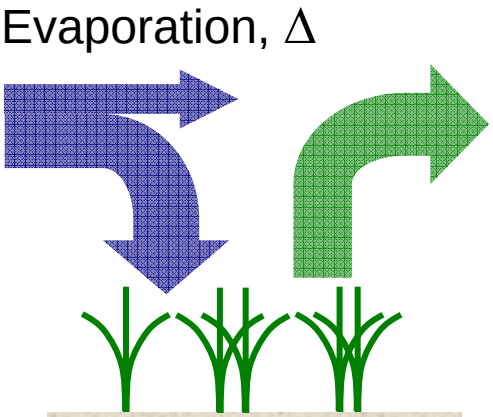
$$\left(\gamma_r \cdot \rho_r \cdot RLD\right)\Big|_{Z_r} = WUE \cdot \frac{d\langle T(Z_r) \rangle}{dZ_r}$$

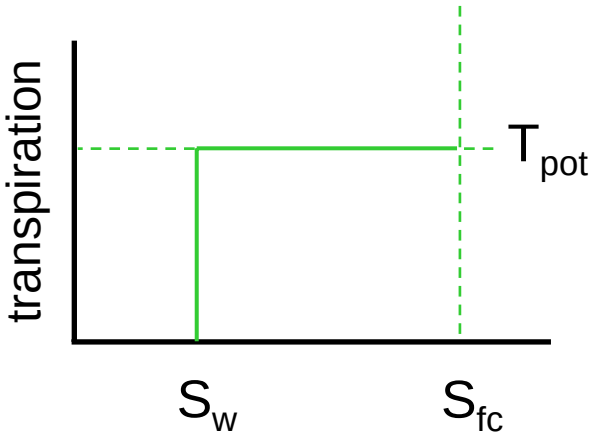
Goals

- Predict root depth as a function of the intermittency and depth of rain events in both wet and dry environments.
- Develop a simple model that enables analytical solution.
- Illustrate the impacts of a changing climate on root depth and flux partitioning if water acquisition drives morphology.

Simple model for soil-moisture







Climate	
α	mean depth of rain
Δ	depth of evaporation
λ	frequency of infiltration
T_{pot}	potential transpiration

Root zone

Depth, Z_r

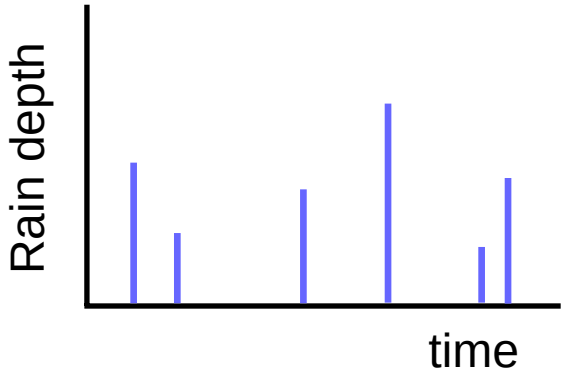
Porosity, n

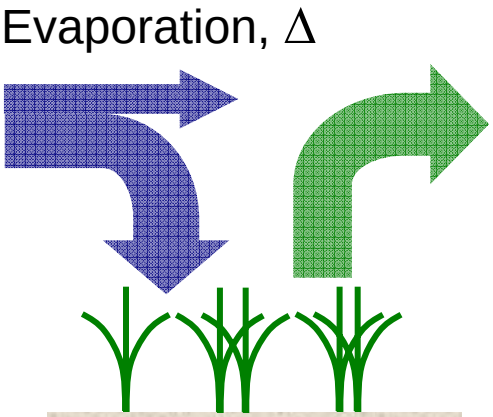
Field capacity, S_{fc}

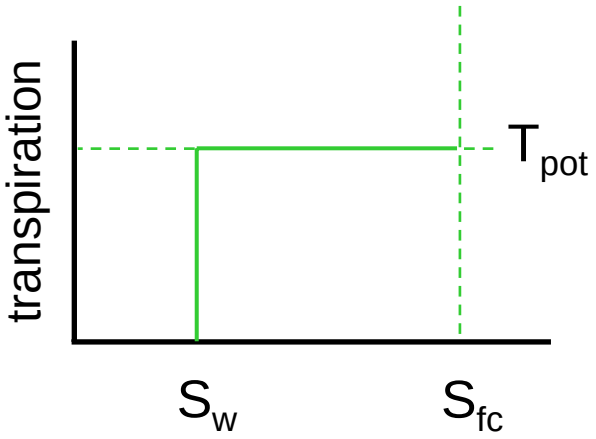
Wilting Point, S_w

Soil	
n	porosity
S_{fc}	field capacity
S_w	wilting point

Simple model for soil-moisture







Climate	
α	mean depth of rain
Δ	tion
λ	
T_{pot}	potential transpiration

$$W = \frac{\alpha\lambda}{T_{pot}}$$

Root zone

Depth, Z_r

Porosity, n

Field capacity, S_{fc}

Wilting Point, S_w

Soil	
n	porosity
S_{fc}	
S_w	wilting point

$$\theta = n\left(S_{fc} - S_w\right)$$

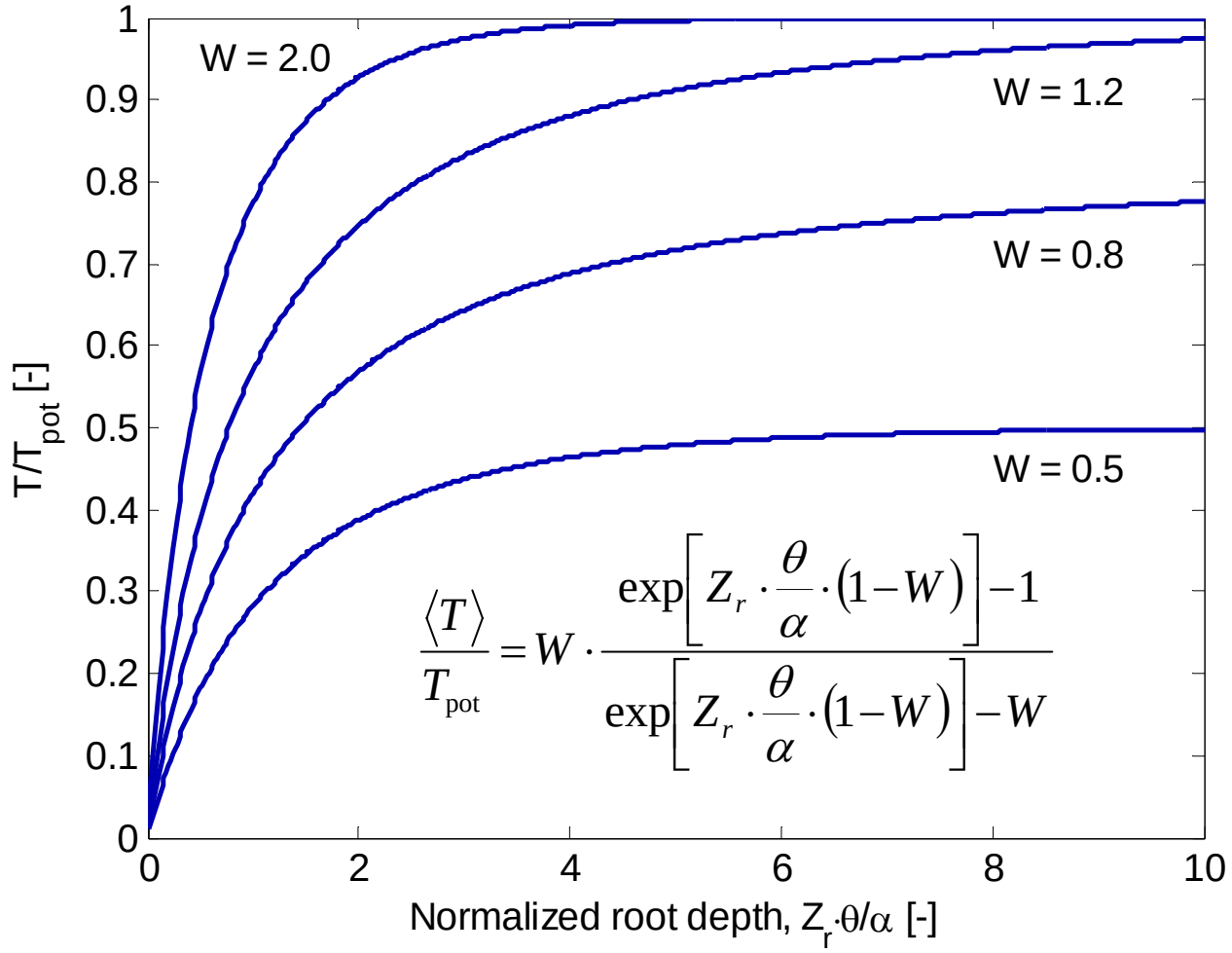
Recap simple model for soil-moisture dynamics

Rainfall – stochastic, instantaneous, characterized by depth and frequency.

Infiltration – root-zone absorbs all water up to field capacity; any remainder is lost to drainage or runoff.

Plant Uptake – for root-zone saturation above the wilting point, transpiration equals the potential rate.

Expected transpiration



Solution from
Milly, P. C. D., 1993. An analytic solution of the stochastic storage problem applicable to soil water, *Water Resources Research*, 29(11), 3755-3758.

Benefit and Cost of roots

Vegetation	
WUE	water-use efficiency
RLD	root-length density
ρ_r^{-1}	specific root length
γ_r	root respiration

$$B(Z_r) = WUE \cdot \langle T(Z_r) \rangle$$

$$C(Z_r) = \int_0^{Z_r} \gamma_r \cdot \rho_r \cdot RLD \cdot dz$$

Marginal benefit equals marginal cost when

$$\gamma_r \cdot \rho_r \cdot RLD = WUE \cdot \frac{d\langle T(Z_r) \rangle}{dZ_r}$$

Water-Optimal Depth

$$Z_r = \frac{\alpha}{\theta(1-W)} \ln X$$

$$X = W\left(1 + Y \pm \sqrt{2Y + Y^2}\right)$$

$$Y = \frac{\theta}{\alpha} \frac{(1-W)^2}{2A}$$

$$A = \frac{\gamma_r \cdot \rho_r \cdot RLD}{WUE} \cdot \frac{1}{T_{pot}}$$

Water-optimal root depth depends on three variables

$$W = \frac{\alpha\lambda}{T_{pot}}$$

Wetness of the climate

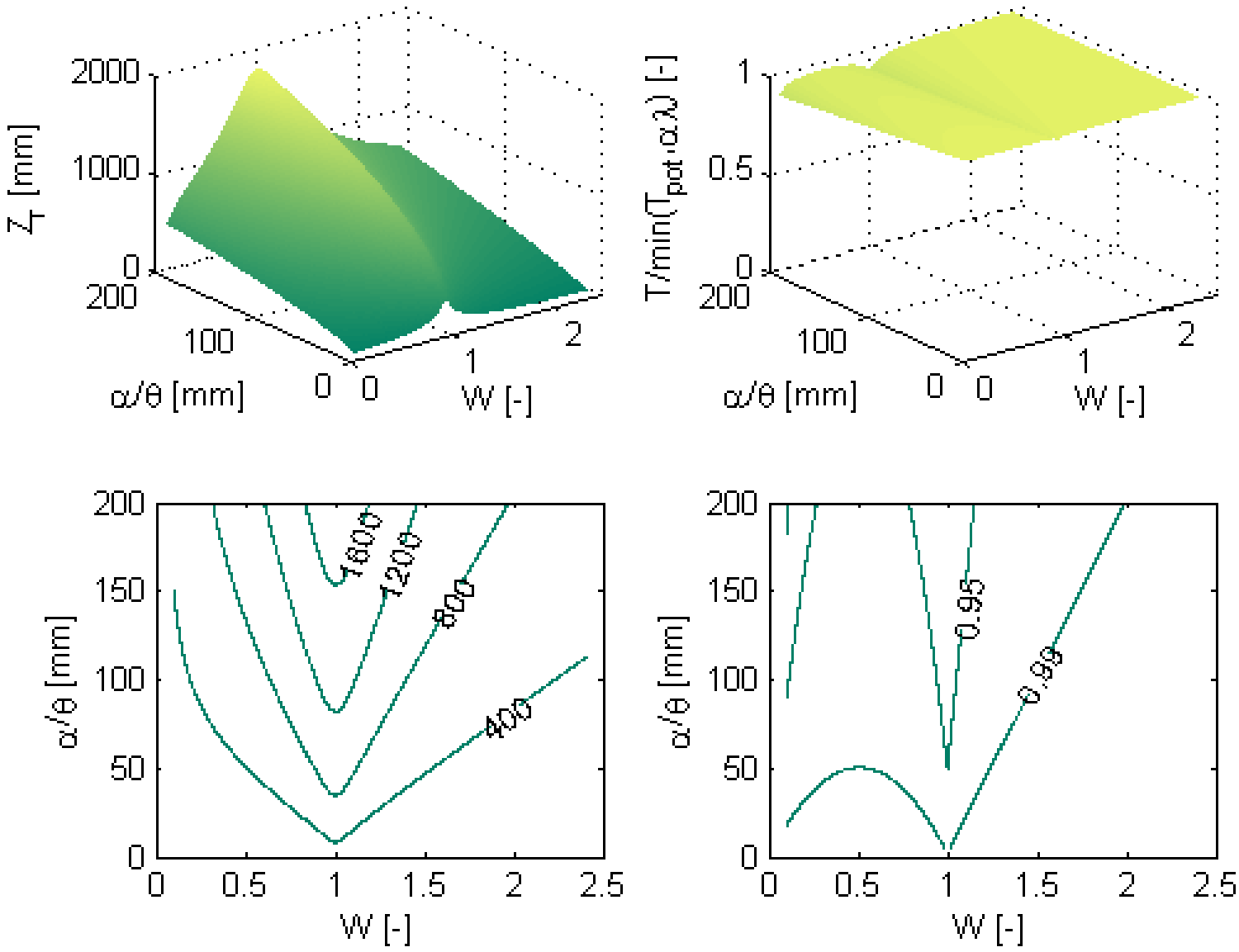
$$\frac{\alpha}{\theta} = \frac{\alpha}{n\left(S_{fc} - S_w\right)}$$

Characteristic infiltration depth

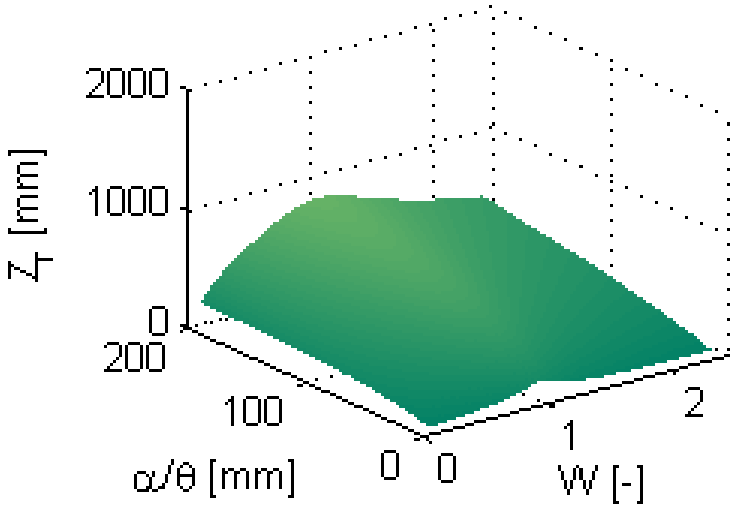
$$A = \frac{\gamma_r \cdot \rho_r \cdot RLD}{WUE} \cdot \frac{1}{T_{pot}}$$

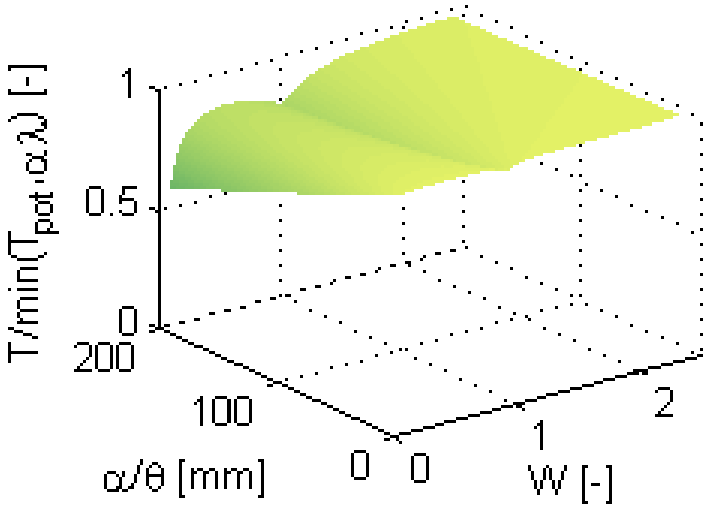
Relative root cost

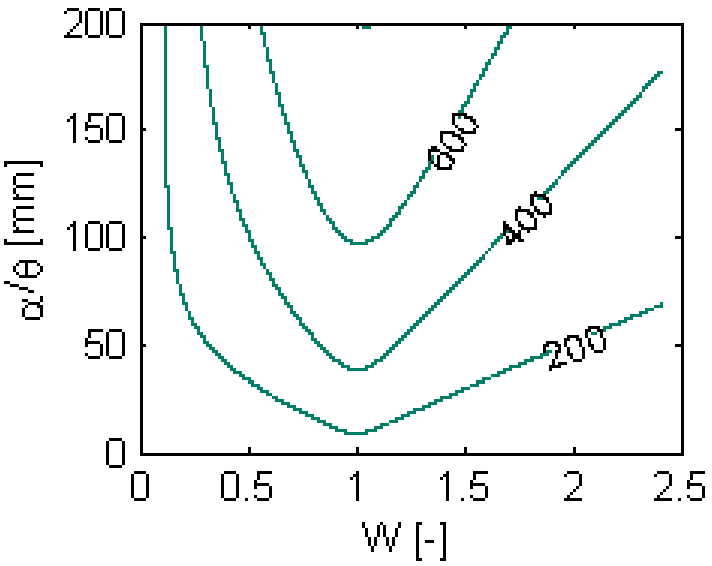
$A = 5 \times 10^{-5}\ mm^{-1}$

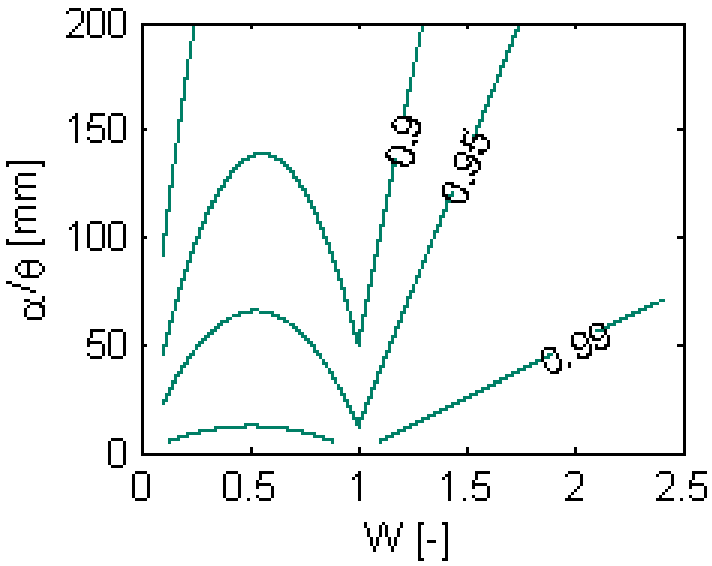


$A = 2 \times 10^{-4}\ mm^{-1}$

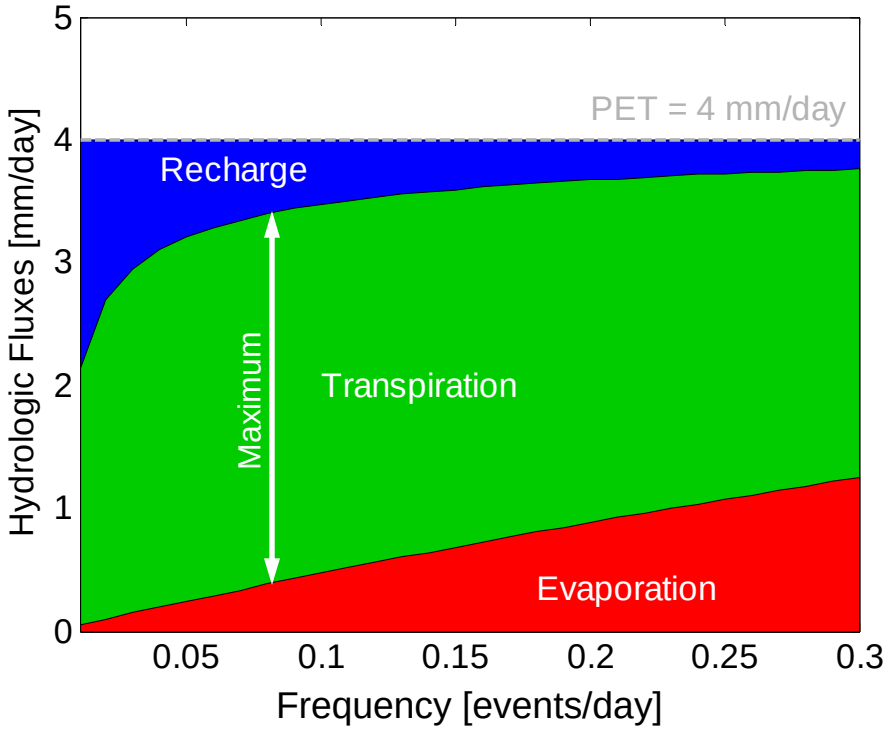


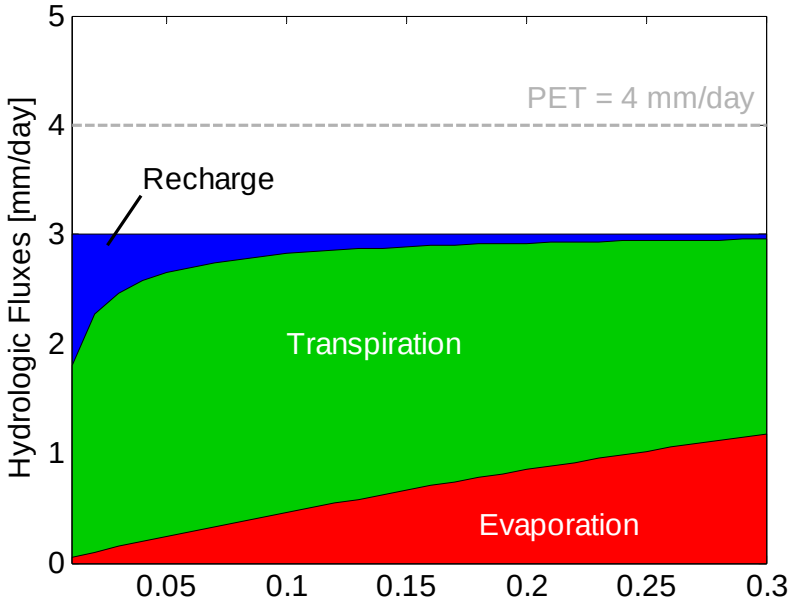


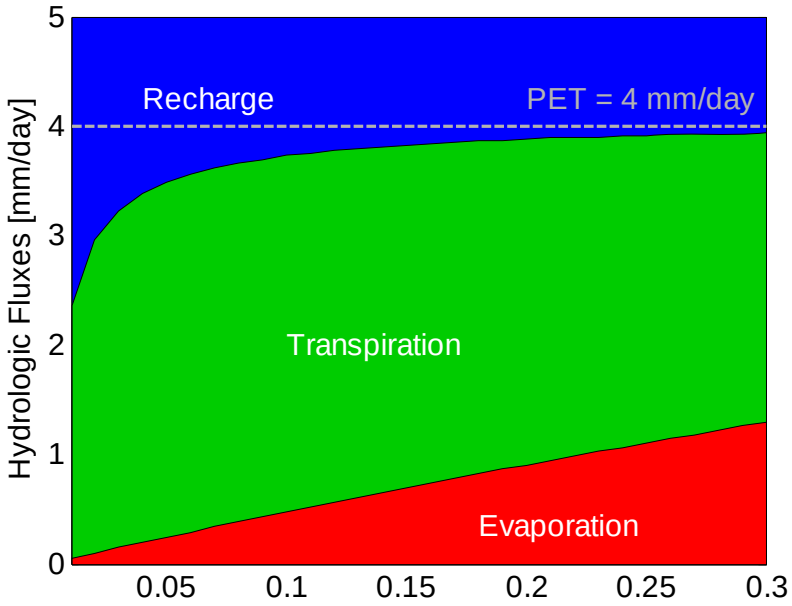




For a given average rainfall and evaporative demand, how does precipitation frequency affect the partitioning of fluxes?



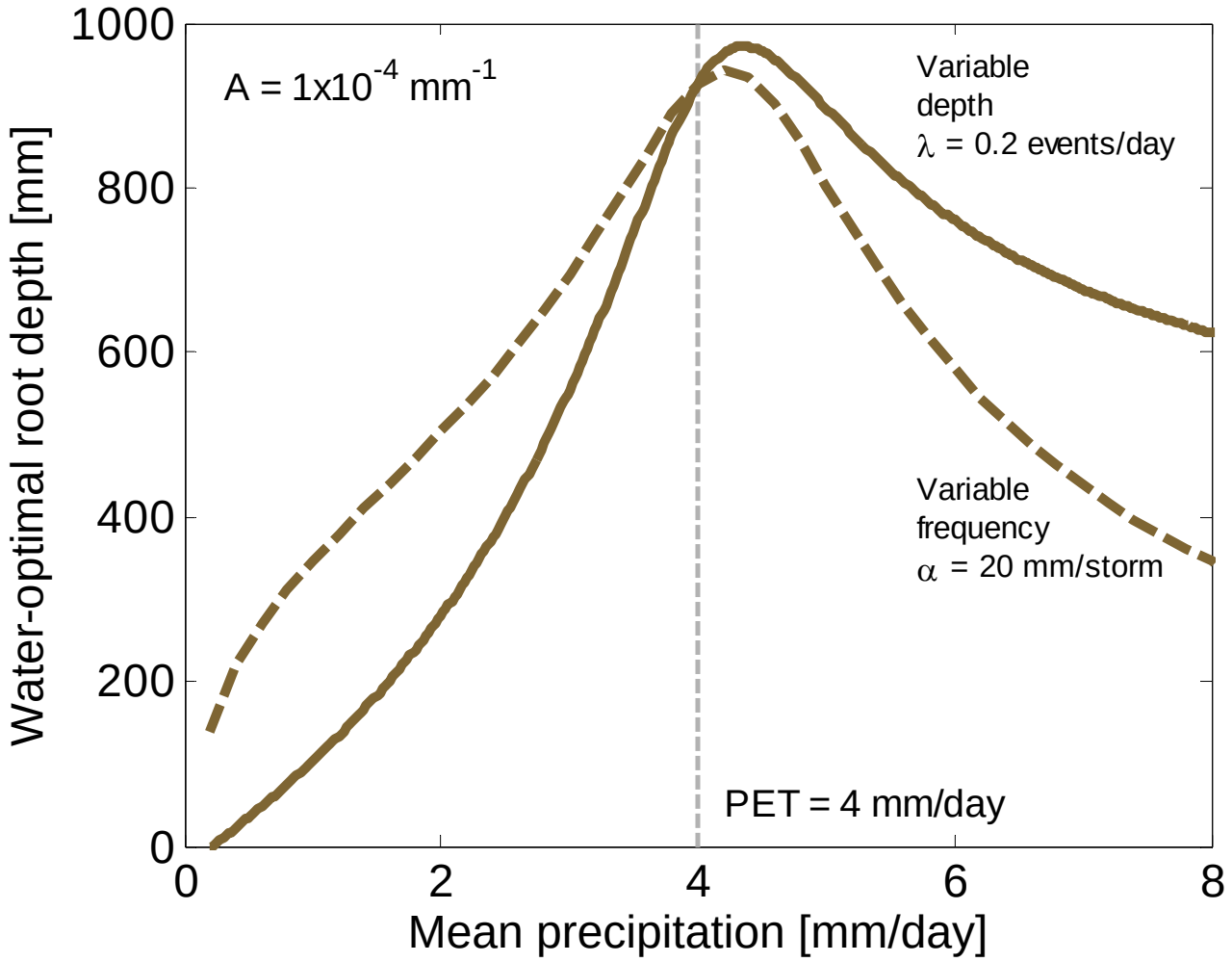




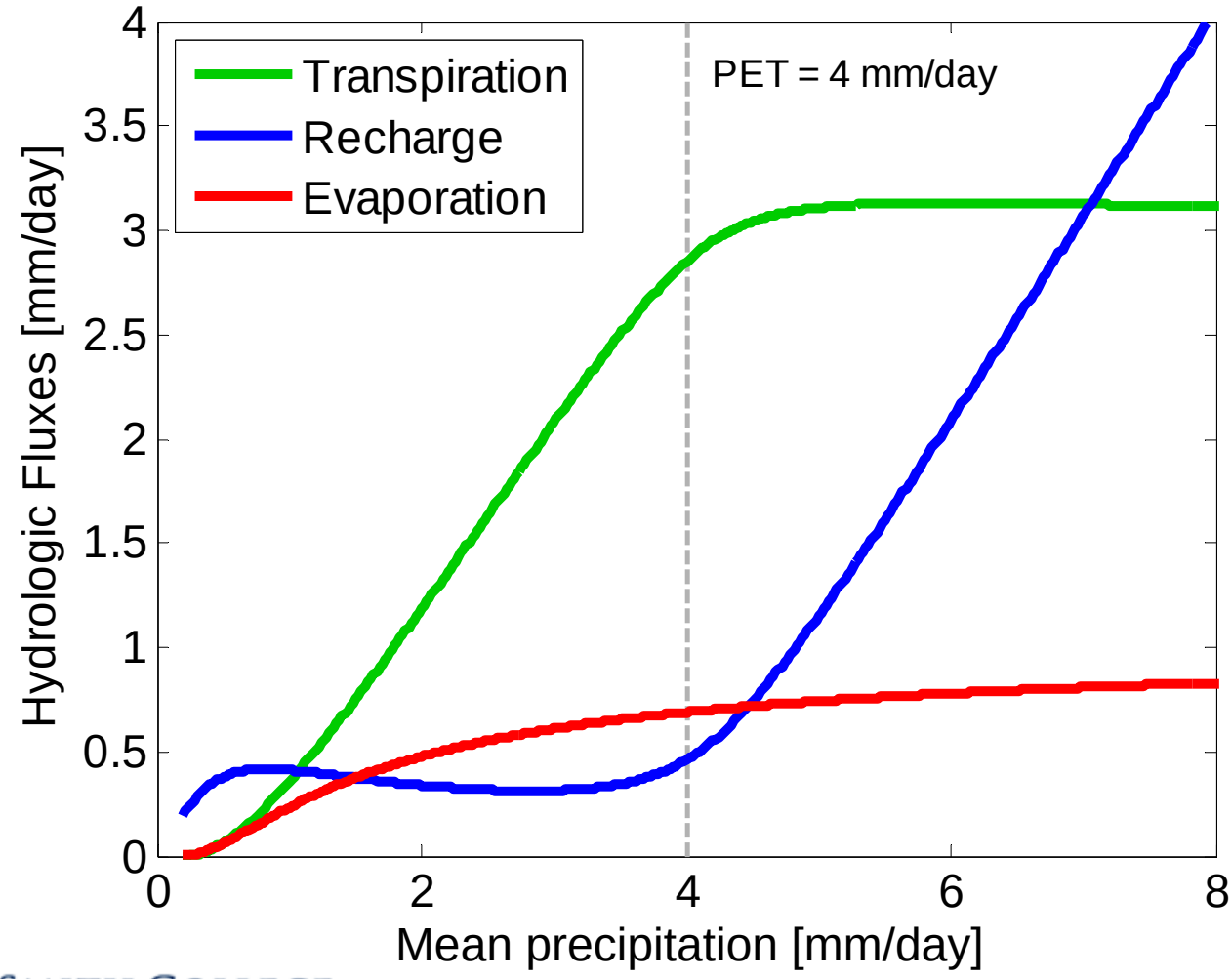
SMITH COLLEGE

Andrew J. Guswa

Sensitivity of Root Depth to Wetness

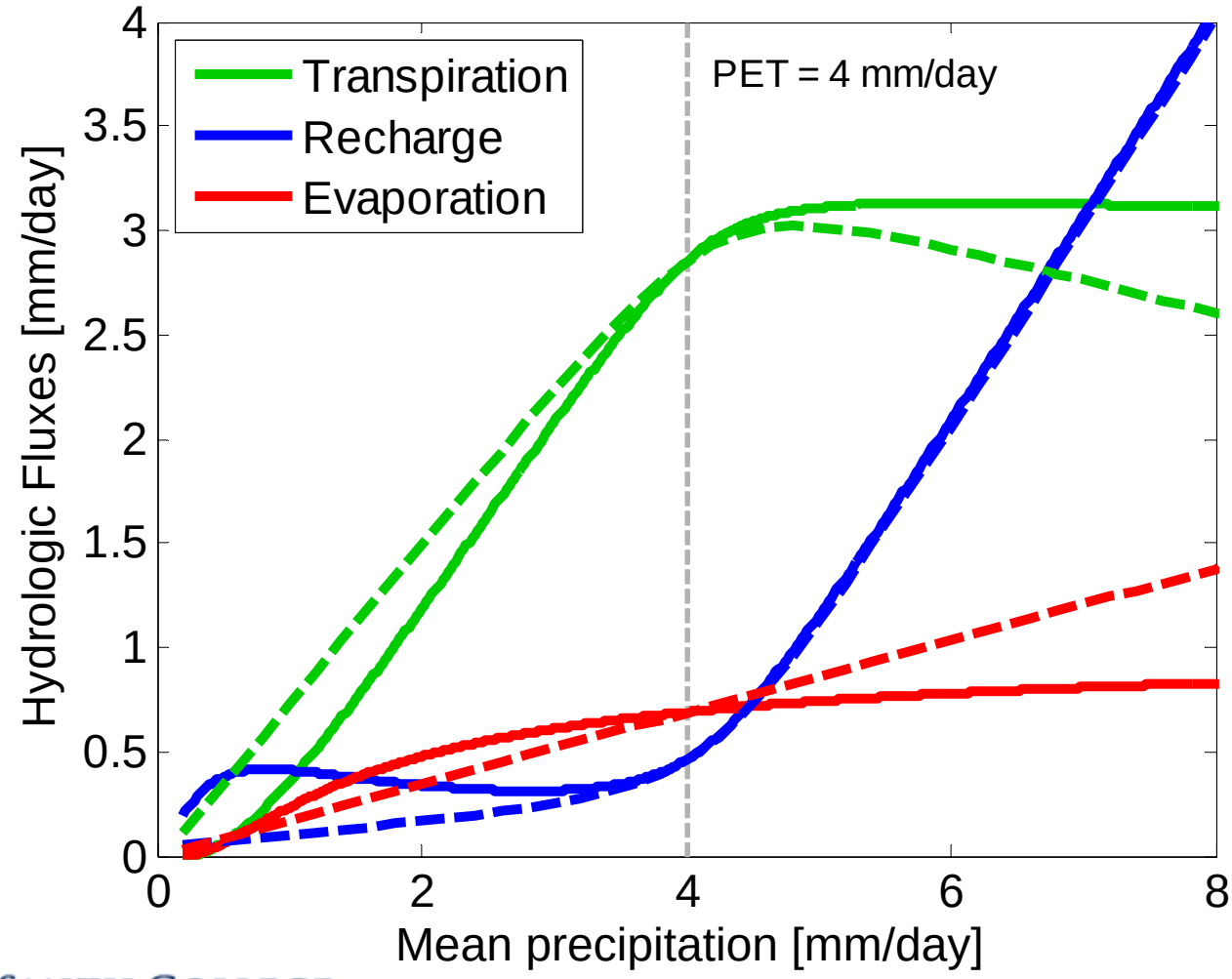


Sensitivity of Flux Partitioning to Wetness of Climate



Solid lines – variable rain depth (λ = 0.2 events/day)

Sensitivity of Flux Partitioning to Wetness of Climate



Solid lines – variable rain depth (λ = 0.2 events/day)

Dashed lines – variable frequency (α = 20 mm/event)

Conclusions

- Roots are deeper when rainfall is approximately equal to potential transpiration.
- For a given climate, recharge increases as precipitation becomes less frequent.
- Transpiration is maximized at intermediate rainfall frequencies.
- Root depth is more sensitive to rain *depth* in dry environments and to *frequency* in wet environments.

Questions?