Simulating Stony Soil Impact on Evapotranspiration

Kshitij Parajuli[1], Scott B. Jones[2], David G. Tarboton[1], Lin Zhao[2], Gerald Flerchinger[3]

[1]Dept. of Civil and Environmental Engineering, Utah State University, Logan, UT

[2]Dept. of Plants, Soils and Climate, Utah State University, Logan, UT

[3]Northwest Watershed Research Center, USDA-ARS, Boise, ID

UtahState University DEPARTMENT OF PLANTS, SOILS, & CLIMATE

USDA

Abstract

- ❑ Fewer studies of evapotranspiration are made in natural vegetation ecosystems as compared to agricultural settings.
- ❑ Forest soils in particular, in many locations are dominated by high stone content, affecting the hydraulic soil properties.
- ❑ Variable soil hydraulic properties greatly complicate the understanding and simulation of water and energy fluxes within the land surface and the atmosphere.
- ❑ The Hydrus-1D numerical model was employed to simulate evapotranspiration (ET) from stony soil.
- ❑ Two different scenarios for stony soils were simulated here assuming highly porous- (porosity = 35%) and negligibly porous- (porosity = 3%) stones in the soil.
- ❑ Simulated ET was overestimated compared to eddy covariance measurements when neglecting stone content.
- ❑ Accounting for stones substantially reduced simulated cumulative ET due to the reduced bulk soil water retention.

Theoretical Consideration

Stone fragments in soil affect soil water retention properties. However, stone fragment water retention capacity is commonly neglected. *Parajuli et al. (2017)* quantified the water retention for common stone types and expressed the bulk stony soil water retention as :

$$\theta_{mix}(h) = (1-v)\theta_{soil}(h) + v\theta_{stone}(h) \qquad (1)$$

where,

- θ_{mix} — *bulk volumetric water content of a stony soil* volumetric [$L^3 L^{-3}$]
- h — *matric potential [L]*
- v — *volumetric stone content* [$L^3 L^{-3}$]
- θ_{soil} — *volumetric water content of fine soil fraction alone* [$L^3 L^{-3}$],
- θ_{stone} — *volume fraction of stone fragments (stone content)* [$L^3 L^{-3}$],

The HYDRUS-1D (H1D) numerical model was used to simulate water transport in unsaturated porous media (Simunek et al., 2008). The H1D model for one-dimensional uniform water movement is described by the modified Richards equation, written:

$$\frac{\partial\theta(h)}{\partial t} = \frac{\partial}{\partial z}\left[K(h)\left\{\frac{\partial h}{\partial z}+1\right\}\right] - S \qquad (2)$$

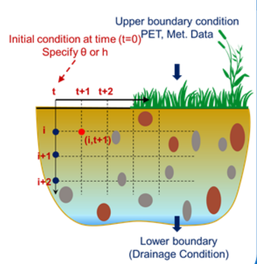
where

- θ — *volumetric water content [$L^3 L^{-3}$],*
- z — *vertical coordinate [L],*
- t — *time [T],*
- K — *unsaturated hydraulic conductivity [$L\,T^{-1}$], and*
- S — *sink term representing root water uptake (RWU) [T^{-1}].*

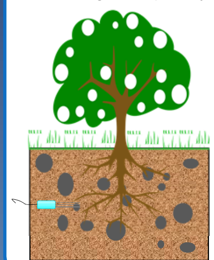
The *θ(h)* and *K(h)* are the water retention and the hydraulic conductivity functions and defined by the van Genuchten-Maulem Model (*van Genuchten 1980; Mualem 1976*).

Upper boundary is defined by the meteorological condition and the time variable precipitation input.

The potential evaporation is used as an input to calculate the actual evaporation fluxes based on Feddes reduction for transpiration and hCritA limit for soil evaporation (Simunek et al., 2008).



- ❑ The porosity of stones may vary from near 0% to values approaching 60% in pumice, for example.
- ❑ Two different scenarios of stony soil were assumed here,
  - Highly porous stones (n = 35%).
  - Negligibly porous stones (n = 3%).
- ❑ Evapotranspiration in stony soil was simulated using the H1D model assuming a dual porosity soil hydraulic model.



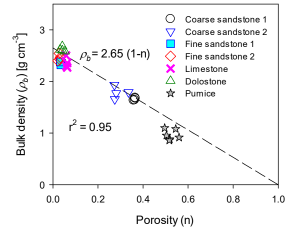
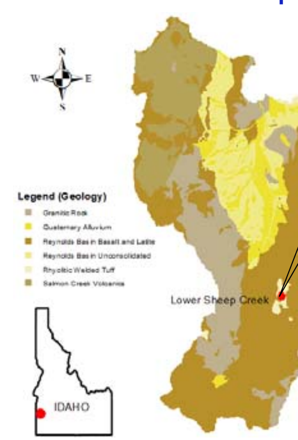


Figure – Bulk density vs. porosity of different stones.

Site Description



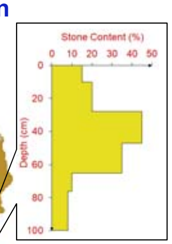


Figure: (a) Study area (Lower Sheep Creek), Reynolds creek watershed. (b) Stone content along the soil profile at pit close to soil moisture sensors (c) Met. Station in one of the site in Reynolds creek.

- ❑ The Lower Sheep Creek station is located in the Reynolds Creek Experimental Watershed (RCEW), Idaho
- ❑ The RCEW is a Critical Zone Observatory (CZO), characterized by highly stony soil (average stone content = 0.25 $m^3 m^{-3}$).
- ❑ The Dominant vegetation is *Artemisia arbuscula* (Low sage)
- ❑ Model simulations used meteorological data (relative humidity, wind speed, temperature, precipitation, solar radiation), Soil Moisture and were compared with Eddy Covariance (EC) water vapor flux data.

Acknowledgements

This research was supported by the iUTAH project funded through NSF EPSCoR grant EPS 1208732 awarded to Utah State University, as part of the State of Utah Research Infrastructure Improvement Award. Any opinions, findings, and conclusions or recommendations expressed are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Results

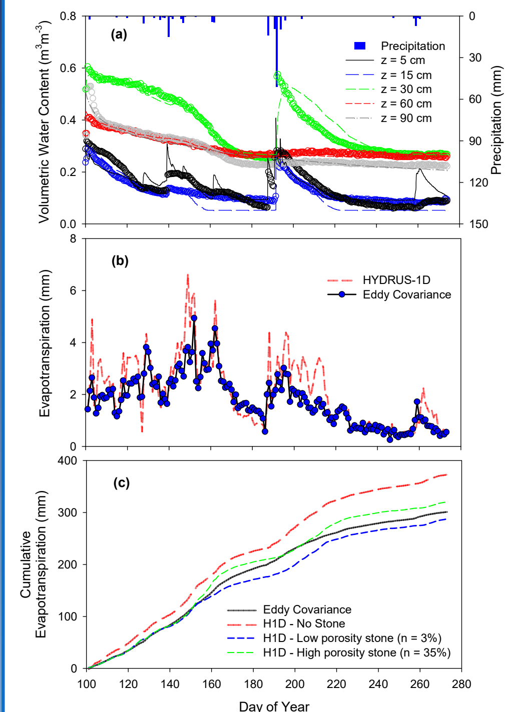


Figure: (a) Time series of measured volumetric water content and H1D simulation. (b) Time series of ET measured with EC and simulated by H1D assuming no soil stones (c) Cumulative evapotranspiration measured by EC and simulated by H1D assuming 1) no stones, 2) highly porous stones and 3) negligibly porous stones present.

Table: Cumulative ET for eddy covariance measurements and for each scenario over the growing season (10 April – 30 September, 2015)

Method	Cumulative ET (mm)
EC Measurement	303.3
H1D - No Stone	374.9
H1D - Low Porosity Stone (n = 3%)	287.5
H1D - High Porosity Stone (n = 35%)	320.5

- ❑ Simulated cumulative ET by H1D was overestimated by 24% relative to eddy covariance ET when neglecting the presence of soil stones.
- ❑ When considering higher and lower porosity stones, cumulative ET was overestimated and underestimated by 5%, respectively
- ❑ Soil stone presence may significantly reduce water storage potential, effectively reducing evapotranspiration over time.

References

Mualem, Y. (1976). A new model for predicting the hydraulic conductivity of unsaturated porous media. *Water resources research*, *12*(3), 513-522.

Parajuli, K., Sadeghi, M., & Jones, S. B. (2017). A binary mixing model for characterizing stony-soil water retention. *Agricultural and Forest Meteorology*, *244*, 1-8.

Šimůnek, J., van Genuchten, M. T., & Šejna, M. (2008). Development and applications of the HYDRUS and STANMOD software packages and related codes. *Vadose Zone Journal*, *7*(2), 587-600.

Van Genuchten, M. T. (1980). A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil science society of America journal*, *44*(5), 892-898.