Estimation of Groundwater Evapotranspiration from Diurnal Water Table Fluctuation Using a new Expression for Drainable Porosity

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Abstract

In shallow unconfined aquifers, plant evapotranspiration from groundwater (ETg) can be estimated by using the observed diurnal water table fluctuation (DWTF) that normally corresponds to the 24-hour ET cycle. This method critically depends on aquifer storage parameters, drainable(λ_d) and fillable porosity (λ_f) which depend highly on the soil moisture flow conditions above WT. Yet, they are usually estimated using static soil moisture profile above WT. Such approach not only neglects the effect of unsaturated-zone flux but also produce a single value for both λ_d and λ_f which is unlikely in shallow phreatic aquifers. Consequently, substantial error may be incurred in ETg estimated from DWTF when only a λ_d value is used especially when used under highly dynamic conditions (e.g., rainfall events).

In this study, two separate expressions of λ_d and λ_f were used to estimate ETg from DWTF. The new expressions account for the steady vertical soil moisture flux from (ET) and to (recharge) the WT at successive times to estimate λ_d and λ_f. Evapotranspiration from shallow WT was estimated during 2010 and 2011 spring seasons in a potato field in northeast Florida, and the results were compared with the ET values from Penman-Monteith method. It was found that the use of steady state λ_d and λ_f produced much better estimation of ETg as compared to the static-λ_d, which significantly overestimated the ET especially during periods with frequent rainfall. The results suggested that ability to determine separate λ_d and λ_f may enable the use of DWTF method of ET estimation even during periods with precipitation the static-λ_d approach.

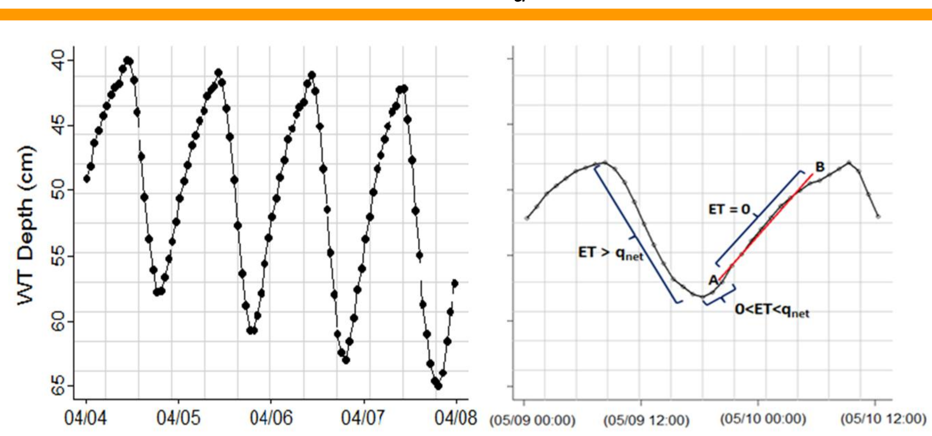


Figure: Observation of distinct diurnal fluctuation in water table due to direct ET loss from WT

Introduction

- Drainable and fillable porosity play critical roles WT fluctuation, hence in ETg estimation from DWTF.
- They are usually estimated assuming static soil moisture profile above the water table which results in a single value for both λ_d and λ_f.
- This may introduce substantial errors especially if used during and after rainfall events since the storage parameters don't account for the effect of unsaturated zone fluxes. To avoid this periods with rainfall are usually omitted in ET estimation from DWTF (e.g., Gribovszki et al., 2007).
- Unsaturated zone flux due to ET and infiltration, however, can significantly affect both λ_d and λ_f. If this effect can be incorporated during their, it can potentially improve ETg estimation from DWTF.
- In this study two separate expressions of drainable and fillable porosity were used to estimate ET form DWTF and compared with the static- λ_d approach.

$$ET_g = q - \lambda_d \frac{dh}{dt}$$

$$q = \frac{4K_{sat}m(2h + m)}{L^2}$$

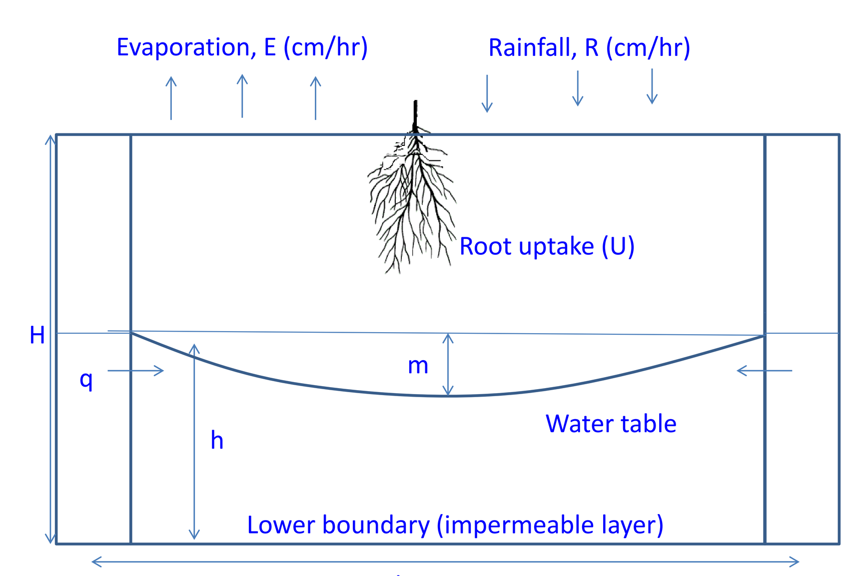


Figure : Conceptual representation of water balance of a soil profile with shallow water table

Hypothesis

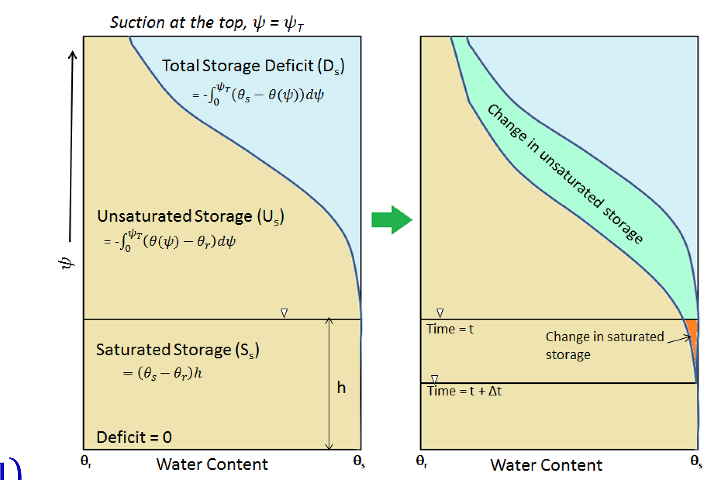
Incorporation of the effect of unsaturated zone flux in λ_d and λ_f estimation will significantly improve ETg estimation even when periods with rainfall are included

Objective

To estimate ETg from DWTF using new flux dependent λ_d and λ_f expressions that account for the effect of unsaturated zone flux above the water table

Drainable and Fillable Porosity

$$\lambda_d = \frac{\Delta S}{\Delta h}; \qquad \lambda_f = -\frac{\Delta D_s}{\Delta h}$$



If a modified van Genuchten model (Troch, 1992) is used to represent the soil moisture retention curve; expressions for λ_d and λ_f under hydrodynamic conditions can be expressed as

$$\lambda_d = (\theta_s - \theta_r)\left\{1 - \left(\frac{d(\psi_T)}{dh}\right)\left[(1 + (\alpha'\psi_T)^{n'})^{-\frac{n'+1}{n'}}\right]\right\}$$

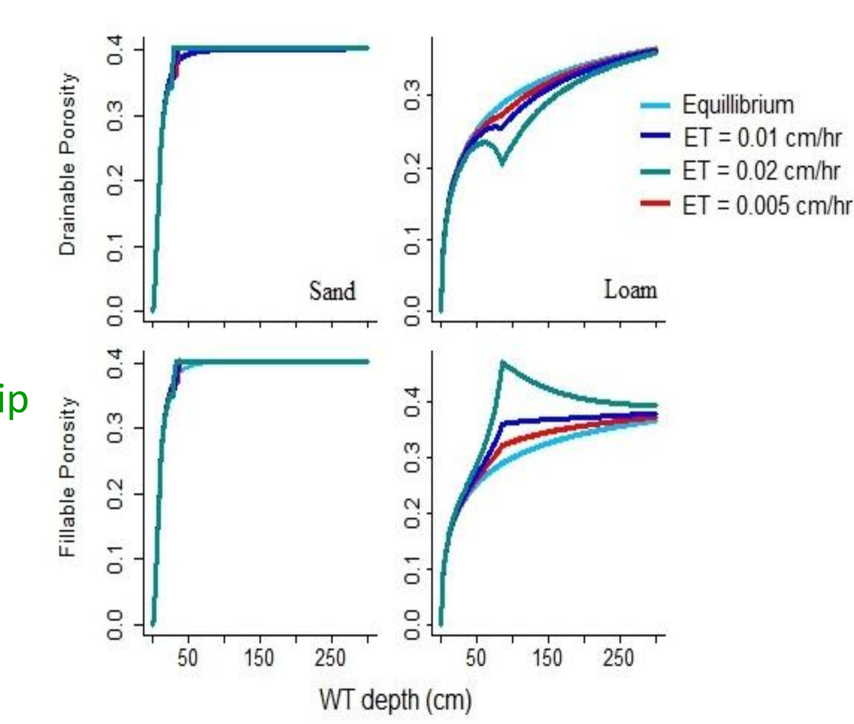
$$\lambda_f = (\theta_s - \theta_r)\left(\frac{d(\psi_T)}{dh}\right)\left[1 - (1 + (\alpha'\psi_T)^{n'})^{-\frac{n'+1}{n'}}\right]$$

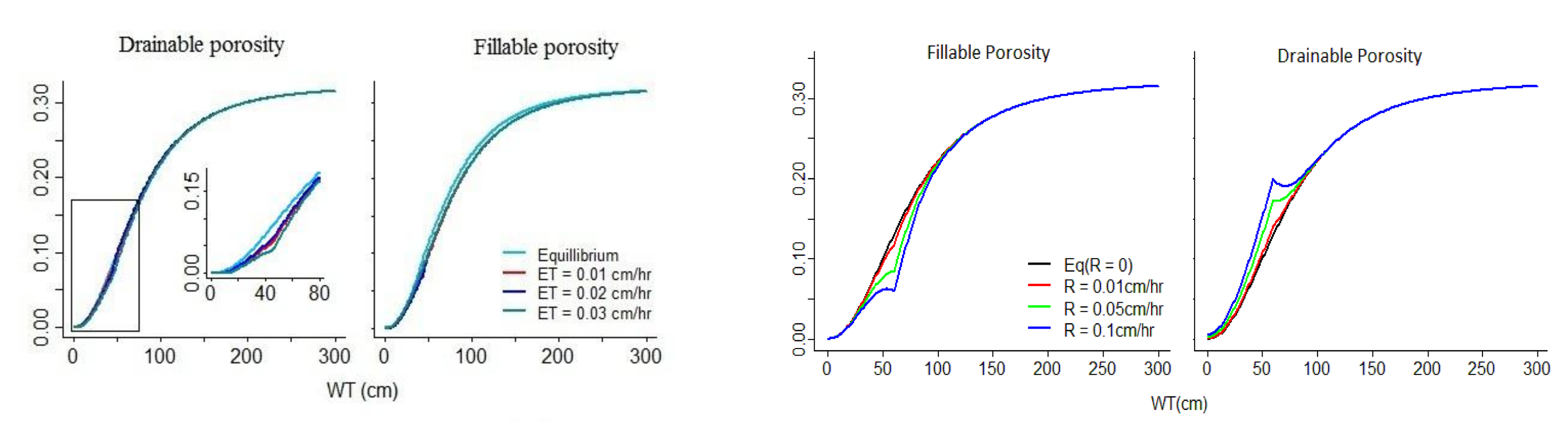
Assuming steady state at successive time steps, ψ_T can be estimated using certain $K(\psi)$ functions; we use exponential (Gardner, 1958).

$$\psi_T = \frac{1}{a_G} ln\left(\frac{(K_s + \mu)\, e^{(a_G(h-H))} - \mu}{K_s}\right)$$

where, μ either evaporation or WT recharge (R_e)

Exponentially decreasing relationship between the water table depth and between ET (Shah et al., 2007) or R_e were assumed to estimate steady state fluxes in the unsaturated zone





Ellzey Fine sand series from northeast Florida

ETg Estimation using λ_d and λ_f

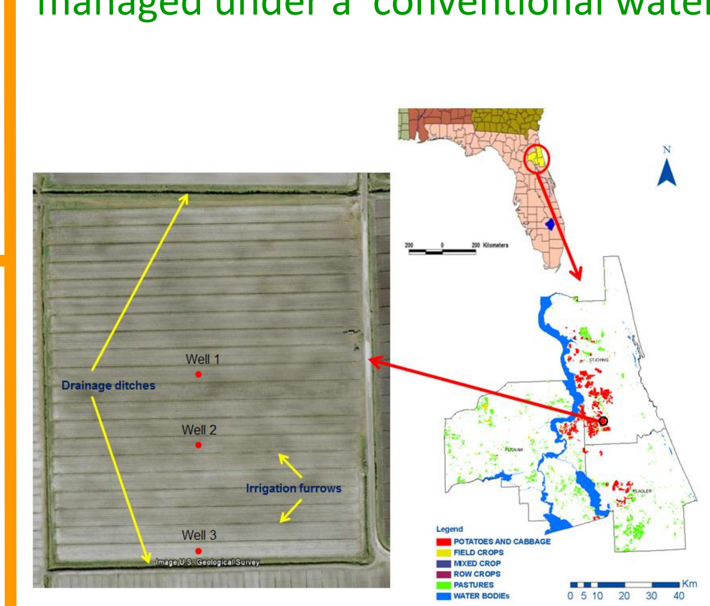
Once λ_d and λ_f estimation method is defined, ETg from DWTF can be estimated as

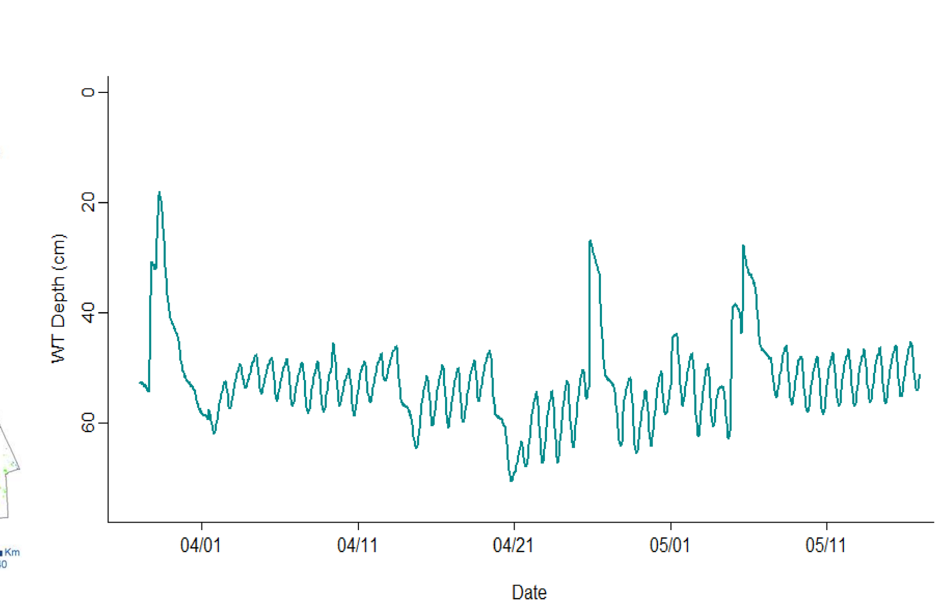
$$ET_g(t) = q_{(t)} - \lambda_d\left(h_{(t-1)}, ET_g(t-1)\right)\frac{dh_{(t)}}{dt}; \quad if\ Rainfall\ (R) = 0$$

$$ET_g(t) = q_{(t)} - \lambda_f\left(h_{(t-1)}, R_{(t)}\right)\frac{dh_{(t)}}{dt}; \quad \text{if R > 0}$$

Field Site and Water Table Data

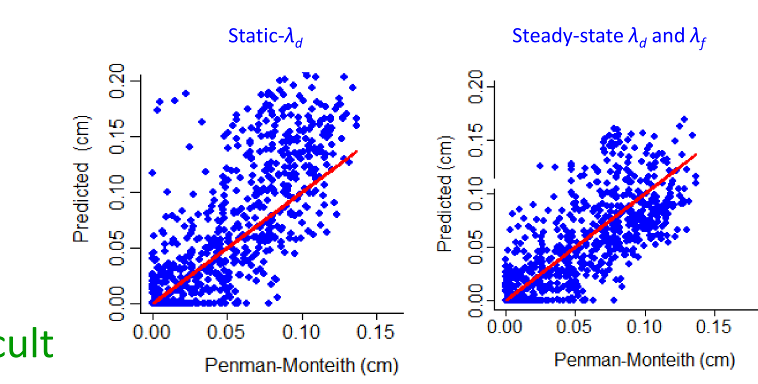
Continuous, 5-10 minute scale WT data collected from a 15ha field in northeast Florida during the spring of 2010 and 2011. The field was planted to potato and managed under a conventional water table control system (seepage irrigation).

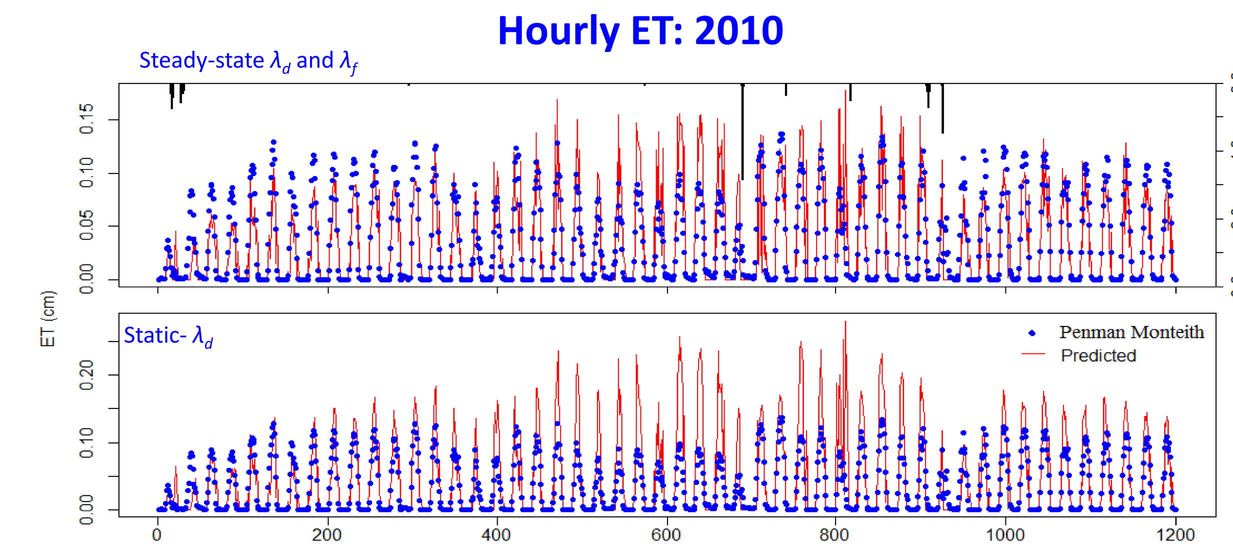




Results and Discussion

- Using flux dependent λ_d and λ_f resulted in significantly better ETg estimations than the static-λ_d in both 2010 and 2011. The estimation was improved during and immediately after rainfall events as well.
- Upward flow due to ET tends to reduce the magnitude of λ_d resulting in quicker WT drawdown than estimated by the static-λ_d. During rainfall, on the other hand, λ_f reduces quickly causing greater WT rise than estimated by the static-λ_d.
- This helps in avoiding overestimation of ETg especially during periods immediately after rainfall event when the WT is close to the surface and ET is occurring at potential rate.
- Although there was substantial error in the estimation of ETg from steady state λ_d and λ_f, approach the improvement over the static-λ_d was significant.
- The discrepancy between the Penman-Monteith ET and the estimated ETg might be partly because of the uncertainty associated with the crop-coefficient which is usually difficult to estimate on a daily basis.





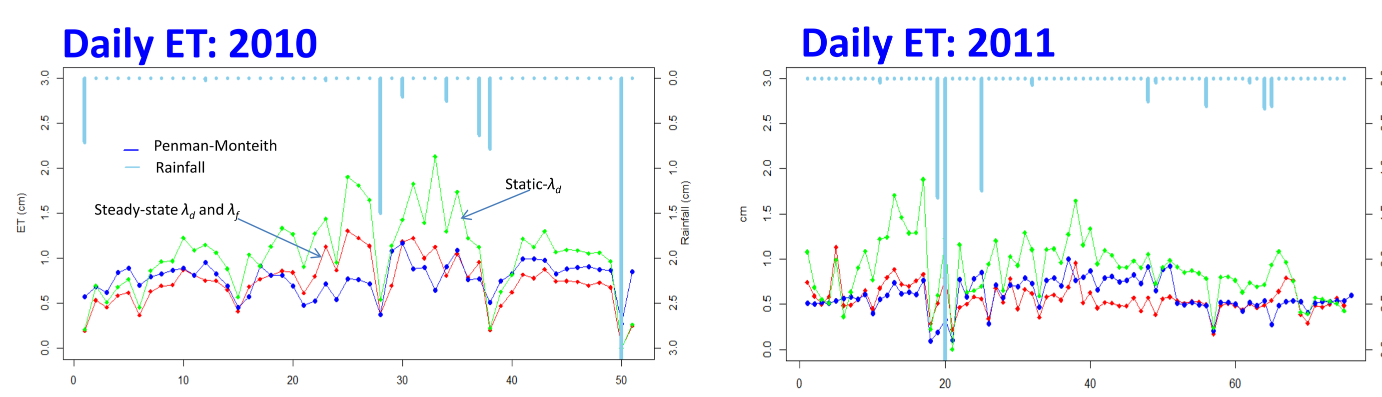


Table: Root mean Square Error (RMSE) of ET estimation for 2010 and 2011 spring season

RMSE (cm)	Steady λ_d and λ_f	Static λ_d
2010		
Hourly ET	0.0009	0.012
Daily ET	0.02	0.28
2011		
Hourly ET	0.001	0.006
Daily ET	0.032	0.16

Conclusions

- Incorporation of the effects of unsaturated zone flux during estimation of λ_d and λ_f may avoid overestimation of ETg from DWTF.
- This approach also enable the use of DWTF method to estimate ETg even during precipitation events. Therefore, it allows for continuous application of the method over longer periods.

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