Simulating Root Water Uptake from a Heterogeneous Vegetative Cover

M. S. De Silva[1]; M. H. Nachabe[2]; J. Šimůnek[3]; and R. Carnahan[4]

Abstract: A small body of knowledge exists on the root water uptake (RWU) and evapotranspiration in humid environments having a mixture of natural vegetative cover. In this paper, we assess the impacts of atmospheric conditions and land cover on RWU from a natural vegetative cover. An intensive field investigation was carried out to monitor water table fluctuations along two flow transects comprising an upland grass area and a lowland riparian zone. Calibration and validation of the soil hydraulic parameters using the two-dimensional variably saturated ground water flow model, HYDRUS-2D, confirms the reliability of the model to simulate satisfactorily the large-scale daily fluctuation of RWU. Simulation results revealed that the actual RWU during the wet season is about 40% higher than RWU in the dry season due to high water table levels and temperatures prevailing throughout the wet season. Simulation results using HYDRUS-2D, which was modified to accommodate variable surface boundary conditions and heterogeneous root distribution, showed that the RWU from the riparian zone was 38 and 56% higher than RWU from the pasture land during the dry and wet seasons, respectively.

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Introduction

On average, about 70% of the mean annual rainfall over the continents is returned to the atmosphere as evapotranspiration (ET) (Bedient and Huber 2002). Despite its significance in any water balance, little research has been carried out to simulate transpiration from catchments comprising heterogeneous vegetative covers (Lawrence 2002; Nachabe et al. 2005). Transpiration, the evaporation of water from leaves' surfaces, is driven by atmospheric conditions, and is limited by the ability of vegetations's roots to uptake available soil water. In most catchments, however, the root water uptake (RWU) varies both spatially and temporally. Spatial variation in RWU is often attributed to the heterogenous root distribution in the rhizosphere reflecting the different plant type covering the landscape. Pasture and grassland have roots that rarely exceed a meter, whereas wooded vegetation have longer roots allowing access to water in deeper subsurface layers. Temporal variability in RWU stems from the continuous change in atmospheric conditions, such as solar radiation, cloud cover, and wind speed. In addition, the spatiotemporal variability of available soil moisture often enhances the variability in RWU. Recently, Vrught et al. (2001a,b) simulated successfully RWU for a small-scale single almond tree. Currently, however, a relatively small body of knowledge exists that applies to watersheds having heterogeneous natural vegetative cover. This is particularly important in Florida and the southeast United States where different vegetation such as pasture, pine prairies, and wooded wetlands coexist naturally within 1 km^2.

In humid environments, such as Florida and the southeastern United States, the water table is shallow, allowing roots to take up water from both a thin unsaturated vadose zone and groundwater. Typically, RWU from phreatophytes—deep rooted plants that extract water directly from the capillary fringe and the water table—suppresses the local water table creating ground water discharge zones. This ground water discharge originates from surrounding landscape and is driven by hydraulic gradients toward the locally suppressed water table. Therefore, heterogeneity in vegetative cover and associated RWU triggers local to medium scale (from ~10 to 1,000 m) subsurface flow in support of the variable RWU over the landscape (McWhorter and Sunada 1985; Nachabe et al. 2005). Indeed, a shallow water table in the discharge zone exhibits diurnal fluctuation: the water table, which declines rapidly during daylight hours due to ET, partially recovers at night by ground water discharge. Diurnal fluctuation in water tables were reported in numerous studies in the past (Meyboom 1967; McWhorter and Sunada 1985; Nachabe et al. 2005).

In Florida, minimum transpiration rates generally occur during the coldest months of the year, whereas maximum rates coincide with the summer season (Hanson 1991). On clear days, the rate of transpiration increases rapidly in the morning reaching a maximum in the early or mid afternoon. Additionally, in Florida's flat topography, a small change in elevation results in significant variation in vegetative cover. Variation of topography and vegetative cover over short scales creates heterogeneous land hydrological response in terms of runoff, ET, and associated RWU.

In this study, water table fluctuations were monitored along flow transects covering two types of vegetative landscapes in

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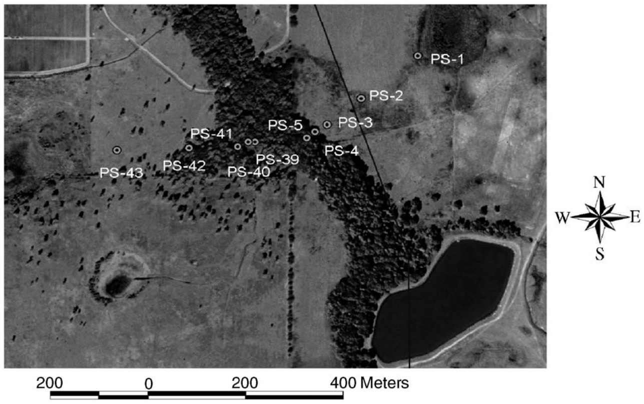

Fig. 1. Aerial photograph of study area showing distribution of observation wells

Lithia, west central Florida. As shown in Fig. 1, the vegetative cover consisted of pasture upland and a riparian zone close to the creek. Observation wells, rainfall gauges, and a total weather station were maintained at the site. These data were collected to calibrate and set the boundary conditions for HYDRUS-2D, a two-dimensional finite-element variable saturation flow model (Šimůnek et al. 1999). Observation wells were distributed along a flow path to capture the subsurface flow between upland and lowland landscapes. This subsurface flow is often driven by the heterogeneous RWU and ET between the different landscapes. Based on additional soil investigation, van Genuchten's (1980) model was fitted to describe the soil hydraulic parameters. The optimization algorithm available with HYDRUS was adopted to fine-tune the soil hydraulic parameters until the observed water table levels agreed with the simulated water table levels. After successful calibration, the model was used to assess the impacts of variable atmospheric conditions and vegetation on RWU for this mixture of vegetation cover.

There were two objectives for this research. The first objective was to demonstrate how, following calibration and validation, a multidimensional variable saturation flow model predicted RWU from a heterogeneous vegetative cover. One dimensional models cannot capture lateral subsurface flow processes in the presence of heterogenous vegetative cover. This was particularly important in environments where landscapes and vegetative covers vary at short scales. The second objective was to assess the impact of variations in atmospheric conditions and vegetation cover on RWU in humid environments with a shallow water table using field data collected at Lithia, west central Florida.

Materials and Methods

Site Description

The study site was in Lithia around the proposed Tampa Bay Regional Reservoir in the southeast Hilsborough county in west central Florida. The predominant soil in the area was Myakka fine sand with pockets of Mulat fine sand, which were characterized by the USDA Soil Conservation Service as deep poorly drained and very poorly drained sands, respectively (Carlisle et al. 1989). The sands at this site were typical west central Florida soils with high permeability in the surface and subsurface layers (Carlisle et al. 1989). The topography varied between +22.9 and +27.4 m above national geodetic vertical datum (NGVD). The surficial water table aquifer is only 4.6 m deep and is poorly connected to the intermediate aquifer below (Thompson 2003). The region of the study area has a humid subtropical climate with a cool dry winter and a warm summer rainy season constituting a strong climate cycle. The average yearly rainfall is 1.57 m. Part of the site has been utilized for cattle ranching and farming in the past.

Two flow paths (transects) on the eastern and western sides of Long Flat Creek were delineated from topographic maps for the area (see Fig. 1). Observation wells were distributed along the transects to monitor water table variability with time. Observation wells from PS1 to PS5 constituted the eastern transect and wells from PS39 to PS43 constituted the western transect. The transects were separated by Long Flat Creek, which runs through the middle of the forested riparian zone in Fig. 1. The eastern transect was 295 m long with an average slope of 1.3% and a total topographic relief of 3.94 m. The western transect was 300 m long with an average slope of 1.2% and a total relief of 3.45 m. The topography of the transect, including location and elevation of each observation well, were surveyed with total station surveying equipment (TOPCON, Tokyo Optical Instruments, Tokyo).

As shown in the aerial photograph in Fig. 1, each transect had a mixture of vegetation. Typically, the upland area (e.g., area PS1–PS4 on the eastern transect) was covered with pasture grass. The vegetative cover changed into a mixture of deep rooted trees in the riparian forested zone close to the creek (e.g., area between PS4 and creek). A variety of species could be identified including Bahia grass, cabbage, scrubs, oak, and maple trees.

Field Data

In order to obtain independent data sets to calibrate and validate the model, an extensive fieldwork was carried out. A high resolution (±2 mm) pressure transducers (Instrumentation Northwest, Inc PS9800) was placed in each observation well to record water table variation. The pressure transducers were connected to data loggers that recorded water table continuously at 5 min intervals. Although gaps existed, graphical presentation and screening of data sets did not reveal outliers for the duration of this study which extended from October 2001 until July 2002. All pressure transducers were calibrated before installation. Also readings from pressure transducers were compared routinely with manual observations of water table levels.

In addition, undisturbed soil samples were collected using hollow stem auger and split-spoon sampling methodology at two locations on the eastern transect (PS1 and PS5) and three locations in the western transect (PS41, PS42, and PS43). Altogether twenty samples at various depths were collected and analyzed in the laboratory (Thompson 2003). Samples were sealed with duck tape to preserve the water content of the samples. Since the textural analysis test is destructive, the conductivity test was done before the texture test. The falling head permeability test was utilized to estimate the saturated hydraulic conductivity. Porosity, sieve analysis, and hydrometer analysis were also conducted to determine textural content (Dane and Topp 2002). These investigations on both transects revealed that soil texture and other physical properties were fairly uniform down to an elevation of 21.3 m (above NGVD) for the eastern transect and 20.9 m (above NGVD) for the western transect, and can thus be represented by one set of soil hydraulic parameters down to this depth. Further, because the underlying layer consisted of clay, this layer could be treated as no-flow boundary in the numerical model.

The land surface boundary was driven by atmospheric conditions, namely rainfall and potential evapotranspiration. At this site, rainfall was monitored using two tipping buckets rainfall gauges that recorded data at 20 min intervals. Due to a technical problem with the data logger on the evaporation pan at the site, the required data to estimate potential ET had to be imported from the Bowling Green weather station about 26 km south east of the site. The South West Florida Water Management District, which maintains this weather station, uses the energy-budget-base Penman–Monteith method to calculate daily potential ET rates.

Finite-Element Model

A two-dimensional finite-element model (Šimůnek et al. 1999) was used for this study. The model is widely accepted in both the research and the engineering communities and has been extensively verified by Šimůnek et al. (1999) by comparing model results with available analytical solutions for solute transport and with other numerical models for water flow. Further, an independent team of hydrologists tested the performance and capabilities of HYDRUS-2D and found the model reliable. The results of their findings were published in the Software Spotlight section of Ground Water (Diodato 2000). Early simulations with HYDRUS-2D showed that the model was appropriate for variable saturation flow modeling in irregular geometric domains (Hernandez et al. 2003). However, research utilizing HYDRUS-2D for simulating large scale RWU had not been previously reported.

The HYDRUS-2D model uses the Galerkin type linear finite-element method for space discretization and a finite difference method for temporal discretization of the two-dimensional variably saturated flow (Richards) equation written as

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

where $\theta(x,z,t)$=water content in the soil $[L^3/L^3]$; $h(\theta)$=matric potential head [L]; z=depth dimension [L]; x=horizontal dimension [L]; $K(\theta)$=unsaturated hydraulic conductivity function [L/T]; t=time [T]; and S=sink term representing the root water uptake [1/T].

Root Water Uptake and Soil Parameters

Generally, two approaches can be used to model the uptake of soil water by roots (Hillel 1998). The first approach, recognized as the single root method, simulates RWU as convergent radial flow towards individual roots treated as cylindrical sinks. The second approach is macroscopic and regards the root system in its entirety as a diffuse sink that permeates each depth layer at varying density. In this study we use the second macroscopic approach and adopt the α-model defined by Feddes et al. (1978) to simulate the RWU. The actual root water uptake term S in Eq. (1) is defined as

$$S(h)=\alpha(h)S_p \quad (2)$$

in which S_p=maximum RWU rate $[T^{-1}]$ and $\alpha(h)$=dimensionless variable function of soil water pressure head and characterized by four parameters as shown in Fig. 2. The RWU is assumed zero close to saturation (i.e., wetter than some "anaerobiosis point" P0 to represent very low oxygen environment). The root water uptake is also zero for pressure heads less than the wilting point (P3). Reduction of the RWU close to soil saturation and below the wilting point is caused by reduction of oxygen availability and the unsaturated hydraulic conductivity, respectively. Water uptake is

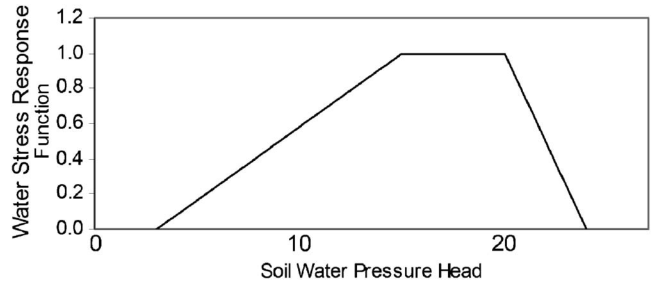

Fig. 2. Schematic of plant water stress response function $\alpha(h)$ (adapted from Feddes et al. 1978)

considered optimal between pressure heads Popt and P2. Root water uptake is also assumed to vary linearly between P2 and P3 and between P0 and Popt. To allow P2 to act as a function of potential transpiration, the model uses two parameters P2H and P2L, which vary according to the potential transpiration rates R2H and R2L. During the simulations following parameter values were adopted from HYDRUS 2D (Šimůnek et al. 1999): P0 =−0.1 m, P3=−80 m, Popt=−0.25 m, P2H=−3 m, P2L=−10 m, R2H=0.005 m/day, and R2L=0.001 m/day. To account for the heterogeneous vegetative cover, different root depths were assigned for the pasture land and the forested area in the model. Initially, root depth was assumed 70 cm for grass and 200 cm for the forested area. The root depth of 200 cm was obtained by examining roots of pushed over trees at the site. Because of the uncertainty in root depth, however, we allowed these parameters to be iteratively adjusted during calibration and optimization.

Soil hydraulic properties characterizing soil water retention and permeability were assumed to be described by an analytical model of van van Genuchten (1980) as follows:

$$S_e(h)=\frac{\theta(h)-\theta_r}{\theta_s-\theta_r}=\frac{1}{(1+|\alpha h|^n)^m} \quad (3)$$

$$K(\theta)=K_sS_e^{0.5}[1-(1-S_e^{1/m})^m]^2 \quad (4)$$

where S_e=effective water content, K_s=saturated hydraulic conductivity, θ_r and θ_s denote the residual and saturated water contents, respectively; and α, n, and $m(=1-1/n)$ are empirical parameters. Hydraulic characteristics defined by Eqs. (3) and (4) thus contain five unknown parameters: θ_r, θ_s, α, n, and K_s.

Parameter Optimization

Inverse methods are typically based upon the minimization of a suitable objective function, (ϕ), which expresses the discrepancy between some observed values and the predicted system response. In our model calibration, we minimized the objective function that contained weighted residuals between the measured and simulated water levels in the observation wells in each transect (Šimůnek et al. 1998):

$$\varphi(b,q,p)=\sum_{i=1}^{n_{qj}}w_{ij}[q_j^*(x,t_i)-q_j(x,t_i,b)]^2 \quad (5)$$

The terms on the right-hand side represents weighted deviations between the measured and calculated pressure heads at different times and locations in the flow domain. The term n_{qj} is the number of measurements in a particular measurement set; $q_j^*(x,t_i)$ represents specific measurements at time t_i for the jth measurement set at location $x(r,z)$; $q_j(x,t_i,b)$ are the corresponding

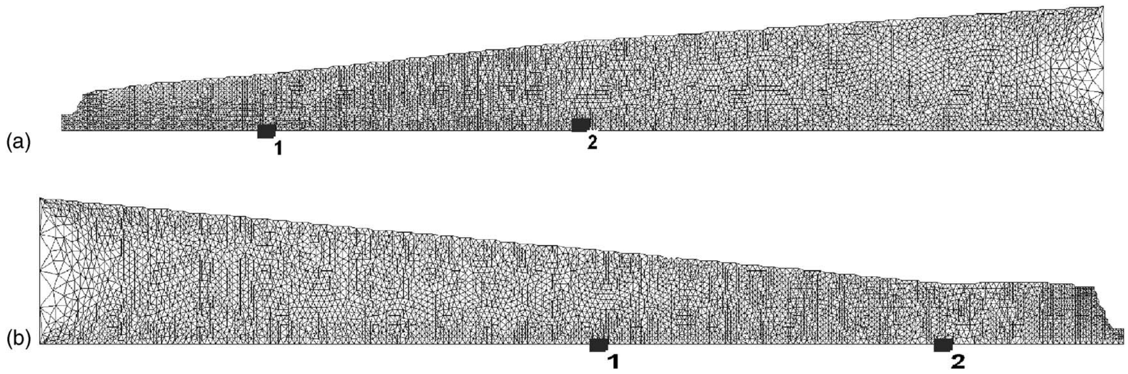

Fig. 3. Finite-element meshes for the geometric domains in the (a) eastern and (b) western transects

model predictions for the vector of optimized parameters b (e.g., θ_r, θ_s, α, n, and K_s); and $w_{i,j}$ are weights associated with a particular measurement set or point, respectively.

Levenberg Marquardt nonlinear minimization method (Marquardt 1963), a weighted least-squares approach based on Marquardt's maximum neighborhood method which combines the Newton and steepest descend methods and generates confidence intervals for the optimized parameters is used to minimize the objective function.

Modification of the HYDRUS-2D Code

The original HYDRUS-2D code simulates a single atmospheric boundary condition such as prescribed precipitation or ET rates for a particular time. The transpiration rate is distributed over the entire root zone to obtain potential local root water uptake rates, $S_p(x,z)$. Also HYDRUS-2D assumes a single root zone is normalized so that it corresponds with the surface area with prescribed atmospheric boundary conditions. For the purpose of this study, the HYDRUS-2D code was modified so that it simulates atmospheric conditions continuously in time (e.g., precipitation followed by ET). Also the code was modified to allow variable rooting depths reflecting the different vegetation in the transect. This last modification was necessary to simulate root water uptake rates for the upland with shallow rooted vegetation (grass) and the lowland with deep rooted vegetation (trees).

Results and Discussion

The finite-element meshes are shown in Fig. 3 for the eastern and western transects. The generated meshes consisted of 5,137 nodes and 11,023 computational elements on the eastern transect [Fig. 3(a)] and 5,113 nodes and 9,795 elements on the western transect [Fig. 3(b)]. We intentionally refined the resolution of the mesh around the creek and close to the land surface to capture the steep hydraulic gradients that were expected to develop from imposing the boundary conditions. Numerical convergence of finite-element simulations is usually dependent on the finite-element discretisation. The finite-element mesh in Figs. 3(a and b) provided stable numerical simulations for this study, because further mesh refinement through adding more computational elements increased computational time without significant change in simulations' results. The upper geometry of the mesh constituted the land surface as determined from the survey for the site. We used the meshes in Fig. 3 for all simulations including model calibration and validation.

The selection of HYDRUS-2D for this study was justified for two reasons. First, the model uses triangular finite-element mesh which captures the irregular shape of the land surface topography forming the upper boundary of the flow transport domain. Secondly, the model accommodates system-dependent boundary conditions which are adjusted continuously depending on the state variable during the simulation. These boundary conditions cannot be specified a priori. Root water uptake is considered a system dependent condition because it depends on soil water content which varies continuously in time. The root water uptake is equal to the potential transpiration when the soil is wet, but the root water uptake can be limited by the lack of moisture in the root zone when the soil is dry (Šimůnek et al. 1999).

Model calibration consisted of adjusting iteratively the soil hydraulic parameters, so that simulated water levels agreed with measured water levels in the observation wells to a desired level of accuracy. Because model calibration, or parameter optimization, was an indirect approach for estimating soil hydraulic parameters from transient flow data, independent data were used to validate the calibrated soil hydraulic parameters. It was important to validate the model with a different data set to enhance confidence in its performance. This two-step procedure is often called historical validation. In this procedure, the existing data set is divided into two parts with the first (calibration) part being used to calibrate the model and to estimate all necessary parameters, whereas the second (validation or verification) part of the data set serves to compare predicted and measured data values using the parameters calibrated against the first part of the data set (Šimůnek and de Vos 1999). Thus if simulated water levels are in acceptable agreement with measured water levels for this additional data set, then the model is considered to be validated for given conditions. Once validated, the model can be used to simulate non-measured conditions. The calibration and validation procedure basically consists of three basic steps: data compilation, model calibration, and model validation.

Data Compilation

Due to air entrapment and encapsulation in the unsaturated zone during rainfall, unusually high rises in water table levels were observed. During rainfall and infiltration, these rapid jumps in water table levels were attributed to compression of the air phase between the advancing moisture front and the shallow water table, as revealed by Freeze and Cherry (1979) and Nachabe et al. (2004). The compressed air phase puts pressure on the water table causing the water level in the vented observation well to rise rapidly as explained by Sabeh (2004) for this site. Thus, for a

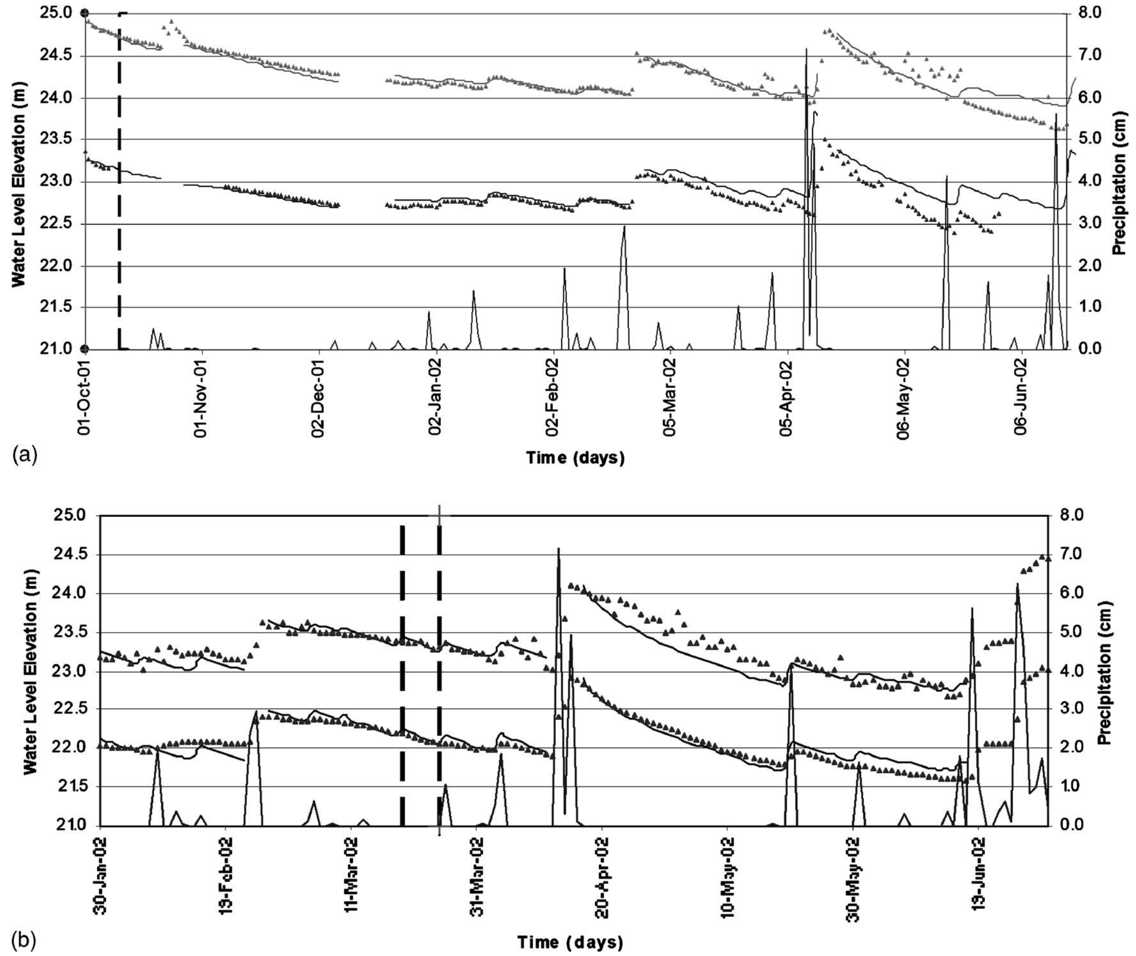

Fig. 4. Observed (dots) and simulated (solid line) water levels with precipitation for the (a) eastern and (b) western transects. Vertical dashed line shows the cutoff period used for calibration.

short period during and following a storm, water level in an observation well may not reflect the actual position of the water table. Because HYDRUS-2D is a one phase flow model which does not simulate the compression of the air phase, periods with no rain were utilized for model calibration. Further, the available zero rainfall periods were scrutinized graphically to avoid erratic records. From the available raw data, daily values of water levels, precipitation, and ET were prepared.

Calibration and Parameter Optimization

The measured soil hydraulic parameters such as porosity, conductivity, and texture were used to initialize van Genuchten's soil hydraulic parameters for the calibration. Initial guesses of the shape parameters were obtained using pedotransfer functions from Rosetta (Schaap et al. 2001), a submodel available in HYDRUS-2D. The optimization algorithm was used to fine-tune root depth and soil hydraulic parameters (θ_r, θ_s, K_s, α, and n) until the simulated water levels agreed with observed water levels.

The calibration of HYDRUS-2D was based on quantitative comparisons between the simulated and measured water table levels. The value of the correlation coefficient (r^2) was 0.99953 for the eastern transect and 0.99653 for the western transect. This coefficient is a quantitative criterion of the goodness of fit of the model and reflects similar and/or dissimilar trends between observed and simulated water levels. The high (r^2) coefficient suggested a rather good fit, as demonstrated in Figs. 4(a and b) showing the variation of observed and simulated water levels. Calibrated soil hydraulic parameters are given in Table 1. The calibrated soil hydraulic parameters were different for each transect. For example, the saturated hydraulic conductivity (K_s) on the western transect was 2.88 m/day, whereas it was only 0.080 m/day on the eastern transect. These results, however, were consistent with permeability and textural analysis on these transects. The measured average (K_s) using the falling head permeability test for the eastern and western transects were 0.31 and 1.38 m/day, respectively. The difference between the measured and calibrated (K_s) can be explained by considering the anisotropy effect. The falling head permeability test measures only the

Table 1. Calibrated Soil Hydraulic Parameters

	Transect	
Variable	Eastern	Western
Residual water content, $\theta_r(m^3/m^3)$	0.021	0.1098
Saturated water content, $\theta_s(m^3/m^3)$	0.399	0.350
Empirical shape parameter α (1/m)	1.115	0.860
Empirical shape parameter n	2.453	3.709
Saturated hydraulic conductivity, K_s (m/day)	0.080	2.881

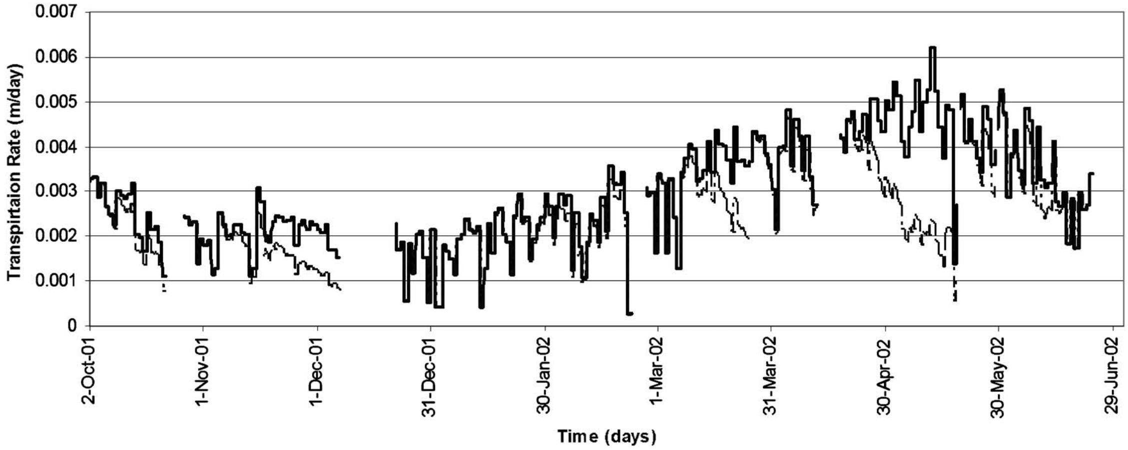

Fig. 5. Seasonal variation of the potential and actual RWU

vertical conductivity and represents local point values. On the other hand, the calibrated parameters represent average effective values over the entire domain. The calibrated saturated water content was larger on the eastern transect (θ_s=0.399 for eastern and θ_s=0.35 for western). The best fit of the n parameter for the eastern transect was lower than that for the western transect. Further, the parameter α for the western part was lower than that for the eastern part.

These deviations were mainly due to the presence of different soil textural classes in the two transects as revealed by soil texture analysis. Fine textured soils dominated the eastern transect, whereas the western part contained more coarse textured soils. Textural analysis, indeed, suggested that soils could be classified as sandy clay on the eastern transect and fine sand on the western transect (Thompson 2003). Variability in calibrated parameters reflected the soil textural differences observed at the site.

Validation

Water level observations from October 1, 2001 to June 27, 2002 and from January 20, 2002 to June 19, 2002 were then used to validate the model for the eastern and western transects, respectively. The validation period for the eastern transect included both dry (October–April) and wet (May–September) seasons. Due to lack of data on the western transect, however, the time period used (January–June 2002) could not capture the seasonal variability. The same finite-element mesh and time steps were utilized, but a different, significantly longer time record of surface boundary conditions was used for validation (see Fig. 4). As for model calibration, boundary conditions were obtained from available rainfall and ET data. The calibrated soil hydraulic parameters were used in the model, and the simulated water levels were compared with the observed water levels.

The simulated water table levels reproduced well the observed water table levels as shown in Figs. 4(a and b). During the dry season, the correspondence between the observed and simulated water levels was exceptionally good, especially for the eastern transect. Although we used water level data for periods with zero rainfall for the model calibration, our results show that we can use the soil hydraulic parameters calibrated during these periods and readily predict also the water level fluctuations after storms. But water level fluctuations following a heavy storm event were less accurately predicted. The reasons for the less accurate estimate of water level fluctuations during storm events could be due to hysteresis and air compression during infiltration (Sabeh 2004) or to the fact that K_s was calibrated with a record that did no contain rain. Therefore, the calibrated K_s could not capture the influences of any macropores that tend to increase the vertical hydraulic conductivity (Nachabe 1995). The inability of HYDRUS to model surface flow was not a factor for these simulations because no runoff was observed at this site.

Seasonal Variation of Root Water Uptake

The transpiration trend for a vegetative cover follows the seasonal cycle of rainfall, solar radiation, and air temperature. The humid subtropical weather at Lithia in west central Florida is characterized by a warm wet season from April to September and a mild relatively dry season from October to March. Over 75% of the rain occurs in the wet season.

Fig. 5 shows the variability of potential and simulated transpiration at the site. As expected, the potential transpiration reflected the climatic seasonality recognized in Florida. Over the course of a year, the cyclic, almost sinusoidal, variability in potential transpiration was attributed to changes in temperatures from the cool dry season when average potential ET hovered at 2.59 mm/day to the hot season with an average potential ET of 4 mm/day. The actual RWU followed the same pattern of seasonality, but was also modified by availability of soil moisture which depended on precipitation patterns. Immediately after storms, RWU was at potential due to the increase in water table levels and associated soil moisture in the root zone. With no rainfall, however, the gradual decline in water table levels was accompanied by a reduction in RWU over time. The lowest RWU was in November and December when both potential transpiration and rainfall were low. When we move from the dry to wet season, both potential transpiration and RWU increased. On average, the actual RWU during the wet season was 40% higher than RWU in the dry season. Simulations results suggested that HYDRUS was able to capture both short time scale variability in RWU associated with arrival of storms, and long term seasonal variability in RWU attributed to seasonality in climate and potential ET.

Spatial Variability in Root Water Uptake

The spatial vegetative cover has a direct effect on the hydrology through its influence on ET and RWU (Dunn and Mackay 1995). As shown in Fig. 1, the simulated site had a mixture of upland

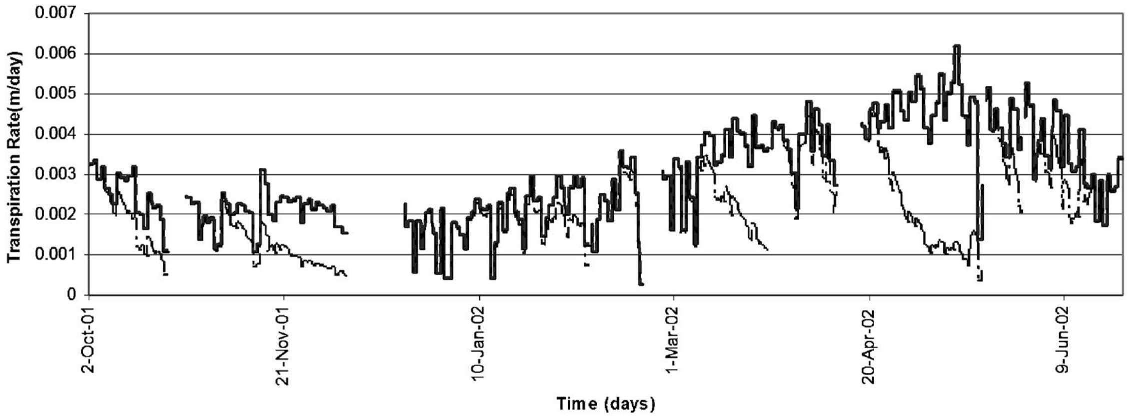

Fig. 6. Variation of the potential and actual RWU in the lowland and upland zones

vegetation with pasture grass and shrubs and a lowland riparian zone with trees. Obviously, vegetation in the riparian zone has higher biomass and deep penetrating roots allowing the plants to access moisture from the deeper layers in the soil profile. Fig. 6 shows the variation of the RWU rates for lowland and upland along with the potential ET rates. Results in Fig. 6 reveal that vegetation in the riparian zone did not suffer any moisture stress throughout the period of simulation. The RWU was equal to the potential almost all the time of the year. The position of these vegetation in the landscape—along subsurface drainage pathways and proximity from creek—in addition to their deep penetrating roots kept RWU at potential throughout the seasons of the year. That was not true of the upland pasture grass areas. The RWU for these areas was close to the potential for few days after a rainfall storm, but declined gradually afterward. It seems these shallow rooted plants were more vulnerable to rainfall and moisture availability.

The average RWU for the lowland vegetated was 2.59 mm/day during the dry season and 4.08 mm/day during the wet season. Those variations reflected the potential ET seasonal variability in Florida. The corresponding values for upland was 1.87 mm/day for the dry and 2.61 mm/day during the wet season. Obviously the differences in RWU for pasture grass and forested areas were attributed to heterogeneity in rooting depth and available soil moisture. In this study area, the dry season is associated with low temperatures and low rainfall whereas the wet season had high temperatures. Therefore, the RWU during the wet season is high not only due to high water table levels, but also due to elevated temperatures. With plentiful water and elevated temperatures, a plant consumes more water.

Conclusion

The overall objective of this research was to demonstrate the utility of modeling to assess the impact of variations in weather conditions and vegetation cover on the RWU in humid environments using field data collected at Lithia, west central Florida. Calibration and validation of the soil hydraulic parameters using two-dimensional variably saturated model, HYDRUS-2D, confirmed the reliability of the physically based model to simulate satisfactorily the large scale daily fluctuation of the actual RWU in humid environments with shallow water table. Simulation of water table level fluctuations during the dry season was exceptionally good. During the wet season the correspondence between simulated and measured water levels was fairly good, providing the ability of the initial pressure head conditions to represent the water level on the initial day. Simulation results revealed that the RWU during the wet season is about 40% higher than during the dry season. This difference is not only due to high water level elevations caused by precipitation, but also due to the high temperatures prevailing during the wet season which increases potential ET. Simulation results, obtained using HYDRUS-2D modified to compare the RWU from heterogeneous natural vegetation cover, showed that the RWU from the riparian zone is 38 and 56% higher than from the pasture land during the dry and wet seasons, respectively. Though the presented results are very promising in demonstrating the capability of the HYDRUS-2D model to simulate large scale ET, the model needs to be further modified for large rainfall events to accommodate runoff and overland flow to be able to describe main processes relevant to hill slope hydrology.

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