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SENSITIVITY OF PINE FLATWOODS HYDROLOGY TO CLIMATE CHANGE AND FOREST MANAGEMENT IN FLORIDA, USA

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Abstract: Pine flatwoods (a mixture of cypress wetlands and managed pine uplands) is an important ecosystem in the southeastern U.S. However, long-term hydrologic impacts of forest management and climate change on this heterogeneous landscape are not well understood. Therefore, this study examined the sensitivity of cypress-pine flatwoods hydrology to climate change and forest management by using the physically based, distributed hydrologic modeling system, MIKE SHE. The model was first calibrated and validated with a long-term data set, and then applied using several hypothetical scenarios developed in north central Florida. Our study showed that MIKE SHE could simulate the temporal and spatial dynamics of the shallow ground-water table. The model also identified and confirmed three horizontal ground-water flow patterns at this study site. The modeling results suggested that forest removal and climate change (i.e., warming and drying) would have pronounced impacts on the ground-water table during the dry periods, but these impacts may be minor under wet conditions at this typical flatwoods landscape. At the landscape scale, depressional wetlands may have higher responses to tree removal and climate change than surrounding uplands.

Key Words: ground water, MIKE SHE, modeling, wetland hydrology, wetlands

INTRODUCTION

Flatwoods ecosystems are a mixture of cypress swamps and pine forests, and cover about 50% (about three million hectares) of Florida's forest land (Bliss and Comerford 2002). As an important ecological plant community in the southeastern Coastal Plain, flatwoods provide many unique ecosystem services including ground-water recharge, water quality improvement, wildlife habitat, biomass production, carbon sequestration, and energy redistribution (Clark et al. 1999, 2004, Gholz and Clark 2002).

Past studies suggest that current and future biotic and abiotic changes will have long-term impacts on forest ecosystems through their direct effects on the water cycle (McNulty et al. 1996, Sun et al. 2001). The coastal plain region may be more susceptible to disturbances due to its unique hydrology that is dominated by shallow ground-water tables (Amatya and Skaggs 2001). The shallow ground-water tables reflect the dynamic balances between evapotranspiration (ET) and precipitation (Sun et al. 2002). About 70–80% of annual precipitation returns to the atmosphere as ET in coastal watersheds (Gholz and Clark 2002, Lu et al. 2003, 2005). Therefore, any changes to ET and precipitation will have direct impacts on the ground-water table fluctuation patterns, and potentially the biotic functions.

Traditional paired watershed experiments conducted throughout the southeast provide much of our current knowledge about how a watershed responds to disturbances and alternative land management practices (Sun et al. 2002, 2004, 2005, Jackson et al. 2004, Amatya et al. 2005). However, these studies used a 'black box' approach that focuses on the effects of land management on streamflow measured at the watershed outlets and did not investigate the internal processes within a watershed. Process-based hydrologic models have been increasingly used in hydrological studies (Graham and Butts 2005, Sun et al. 2006). Forest hydrologic studies need to focus on the complex interactions between the hydrologic cycle and other biological processes under a changing environment at multiple temporal and spatial scales.

Hydrologic models for the flatwoods ecosystems have been constructed in the past (Sun et al. 1998a, Mansell et al. 2000, Liu et al. 2005). Other types of models describing wetland hydrology such as DRAINMOD (Amatya and Skaggs 2001) and SWAT (Arnold et al. 2001) are also available. However, those models were mostly used for simulating field scale hydrologic processes and have not been thoroughly evaluated with spatially distributions of water tables. For example, the FLATWOODS model has been successfully applied to both pine flatwoods in Florida and Carolina bay systems in South Carolina (Sun et al. 1998b, 2006), but both studies only evaluated model performances at selected locations.

Modeling the spatial distribution of a ground-water table is rare, because it is unclear how water tables respond to forest management and climate change over space. Climate change has been increasingly recognized as another threat to southern forest ecosystem structure and functions (McNulty et al. 1996, Sun et al. 2002) and wetland hydrology (Amatya et al. 2006). However, few studies have quantitatively evaluated the magnitude of the potential impacts of climate change and variability on the wetland hydroperiod.

The objectives of this study were to: 1) evaluate a process-based, spatially distributed hydrologic model, MIKE SHE, for modeling the shallow ground-water table, and 2) examine the sensitivity of ground-water table depth to forest removal and climate change using the validated model.

METHODS

The MIKE SHE Model

As a first generation of spatially distributed hydrologic modeling system, MIKE SHE is a comprehensive, deterministic, distributed and physically based hydrologic modeling system (Abbott et al. 1986a, 1986b). It simulates the full hydrologic cycle of a watershed across space and time. MIKE SHE can be applied to a wide range of water resources and environmental problems for the simulations of surface-water and ground-water movement, the interactions between the surface-water and ground-water systems, and the associated point and non-point water quality problems. Detailed descriptions of the modeling procedures and mathematical formulation can be found in the MIKE SHE user's manual (DHI 2006) and associated publication (Graham and Butts 2005).

Data requirements for the MIKE SHE model include: 1) topography and landuse data - retention storage, Manning's roughness number, and vegetation distribution (leaf area index (LAI) and rooting depth), 2) soil data - soil depth and hydraulic properties (conductivity, porosity, and soil moisture release characteristics), 3) meteorological data - precipitation and temperature, and 4) boundary conditions. Major outputs of the MIKE SHE model include ET, overland flow, unsaturated soil moisture content, total runoff at selected points in streams, and ground-water levels. Advantages of MIKE SHE model over other existing wetland hydrology models (e.g., FLATWOODS, DRAINMOD, SWAT) in simulating wetland hydrology are: 1) it offers several options to simulate the infiltration processes and water movement in the unsaturated zone, 2) it links databases in a GIS format with a user interface, 3) the program is easy to learn and use, and 4) the model can simulate both wetland and upland lateral movement of surface-water and ground-water flows.

Study Site and Field Data Acquisition for Model Testing

The study site was located about 33 km northeast of Gainesville, Alachua County in north central Florida (Figure 1). A long-term intensive wetland hydrology study was conducted in the 1990s as one of the forest wetland research sites in the southeastern U.S. (Crownover et al. 1995, Sun et al. 2000, Bliss and Comerford 2002). Geology at this site was dominated by Plio-Pleistocene terrace deposits and the Hawthorne Formation with ground slopes ranging from 0 to 1.6%. A shallow ground-water table is located within the 2–3 m deep organic, sandy soil that is perched on top of impermeable blue-green clay layer over 4 m thick. A secondary artesian aquifer is located below the clay layer. The soil type is predominantly Pomona fine sand (Sandy, siliceous, hyperthermic Ultic Alaquods) (Sun 1995, Mansell et al. 2000).

The cypress swamps accounted for about 35% of the study area with wetland sizes ranging from a few square meters to more than 5-ha (Figure 2). Pond cypress (*Taxodium ascendens* Brongn.) dominate the vegetation in the wetland, along with slash pine (*Pinus elliottii* Engelm.) and swamp tupelo (*Nyssa sylvatica* var. *biflora* Sarg.). The upland is dominated by a 29-year old mature slash pine (*Pinus elliotii*) plantation with saw palmetto (*Serenoa repens* Small) and gallberry (*Ilex glabra* Gray) shrubs as the understory (Sun et al. 2000).

The average annual air temperature is 21°C, with a mean monthly low of 14°C in January and high of

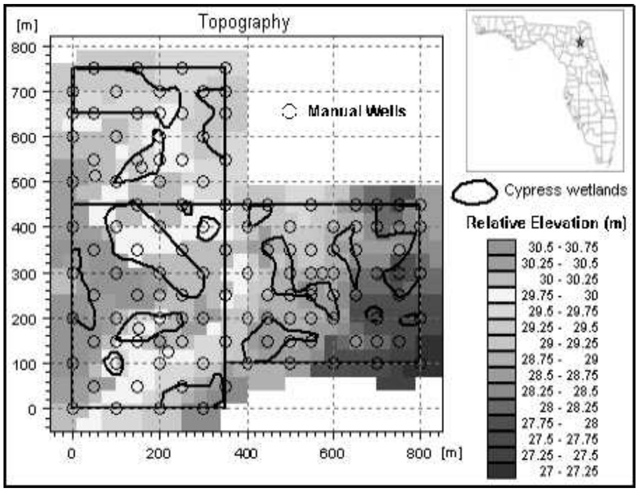

Figure 1. Topography of the Florida wetland site.

27°C in July. Average annual rainfall is about 1330 mm, with two distinct dry periods within a year. The first dry period is from April to June, and the second one is from October to December.

The study site was divided into three blocks: NW, SW, and SE (Figure 2). SW block was not disturbed as a control (C) during 1992–1996. Cypress wetlands in NW block were clear-cut (K) during April–May 1994. Both wetlands and uplands in SE block were also clear-cut (N) during April–May 1994 (Sun et al. 2000).

Beginning in January 1990, the study area was surveyed to establish a 50 × 50 m grid system. An arbitrary datum with the elevation of 30.48 m above mean sea level was set as the reference coordinate (0, 0). The actual elevation of the study site was about 47 m above mean sea level (Sun et al. 2000). Each grid point was marked and labeled with a steel post, and its elevation relative to the datum was measured in the field. Six automatic and 122 manual, 5-cm diameter, 1.5-m long polyvinyl chloride (PVC) shallow water table wells were installed at every second grid point (Figure 1). The bottom 1 m of the PVC pipes had well screening attached to a well point, and the top 0.5 m was a PVC riser with a well cap to cover the aboveground opening. Well depths varied from 1.0 m to 1.4 m, depending on the depth of the argillic horizon and water table height at the time of well installation (Crownover et al. 1995). Water table depths of the 122 manual wells were measured on a set bi-weekly schedule from 1992 to 1995 (Crownover et al. 1995, Sun et al. 1998a).

Within each block, a representative cypress wetland-upland area was selected (Figure 2) and paired automatic wells were installed to continuously record water table depth (Sun et al. 2000). Thus, three wetland and three upland wells with daily

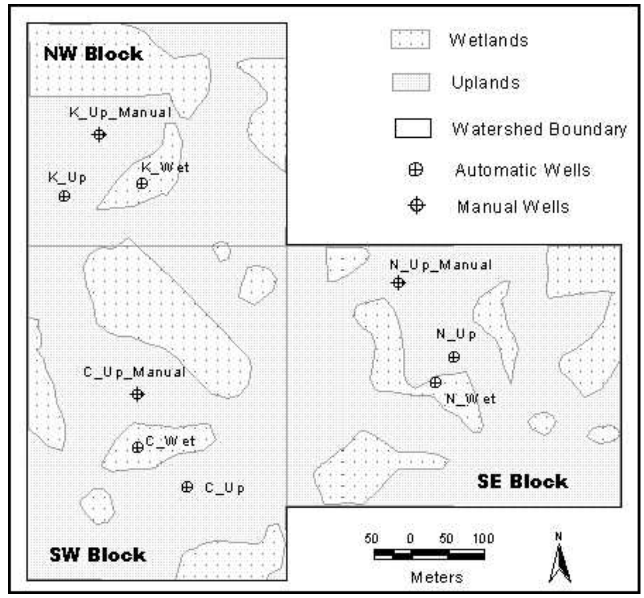

Figure 2. Instrumentation and well locations used in MIKE SHE calibration and validation at the Florida wetland site (C - control; K - only clearcut wetlands; N - clearcut both wetlands and uplands).

automatic recording water table data were used for MIKE SHE model calibration and validation. Among the six automatic recording wells, the three wells that were located in wetlands started recording data on January 23, 1992. However, the other three upland wells did not record data until May 01, 1993. All six automatic wells recorded data until the end of December 1996. In order to fill the data gap between automatic recording wells in wetlands and those in uplands, an additional upland manual well was used for model calibration and validation in each of the three blocks (Figure 2). Data were collected bi-weekly at the three upland manual wells during the period from February 02, 1992 to June 22, 1995. More detailed descriptions of the site establishment, well installations, and earlier data reports can be found in Crownover et al. (1995), Sun et al. (2000), and Bliss and Comerford (2002).

Graphical inspections as a qualitative method and the statistical criteria as a quantitative method were used to evaluate the MIKE SHE model's performance. The statistical parameters included Mean Error (ME), Pearson's Correlation Coefficient (R), and the Nash-Sutcliffe (1970) Coefficient of Efficiency (E). ME is commonly used to determine the average systematic error among the simulated and the observed values. Positive values of ME indicate model under-predictions, while negative values correspond to over-predictions. E varies from minus infinity to 1.0, with higher values indicating better agreement. R is a measure of the strength of the association between observed and predicted values. It may take any value between −1 and 1. Well water table depths at selected location and across the study area were used for model calibration and validation.

The model was calibrated against measured water table data for a wet year (1992) and a dry year (1993) to cover a wide range of water table dynamics. Compared to the long-term annual average precipitation at the site (i.e., 1330 mm in a normal year), the wet year had an increase 170 mm of precipitation while the dry year had a decrease of 230 mm (Sun et al. 1998b). The rest of the water table data (1994–1996) contained a year with dry spring (1994) and two normal years (1995–1996) in terms of total annual precipitation. These data were used for model validation.

In addition to comparing temporal water table dynamics at nine individual locations (Figure 2), spatial discrepancies between simulated and measured water table depths were also examined. Each 'normal day' with measured water table neither too high nor too low was selected to evaluate the model's spatial water table simulations for both calibration and validation purposes. The dates October 29, 1992 and March 11, 1994 were chosen as normal days because water tables were moderate and complete measurements were available over the landscape on these two days. A total of 123 well water table data points were available. The point features of these water table data were interpolated to create a grid surface using the method "IDW, nearest of neighbors, Numbers of neighbors: 3, power: 1, No barriers" using the Environmental Systems Research Institute (ESRI) ArcView 3.3 (ESRI 2002) software.

Simulated spatial water table data on October 29, 1992 and March 11, 1994 were converted from the MIKE SHE text format to an ArcView grid format. Then, this grid was imported into ESRI ArcView 3.3. Water table differences were defined as the spatially interpolated measurement values minus simulated values for the grids examined. The grid subtraction calculations were performed in ArcView 3.3.

After model calibration and validation were conducted, the MIKE SHE model was applied to simulate four hypothetical scenarios to test model sensitivity to extreme impacts from forest management and climate change. These scenarios included: 1) base line (BL), 2) harvesting with clear cutting (CC), 3) a 2°C increase in daily air temperature (TI), and 4) a 10% decrease in daily precipitation (PD).

The BL scenario was based on historical climatic data with the assumption that the site remained forested throughout the study period. The CC scenario represented a simple forest management practice that was also based on historical climatic data but with the assumption that the entire site was clear-cut with leaf area index (LAI) reduced to 0.1 and 0.4 for uplands and wetlands, respectively (Gholz and Clark 2002, Clark et al. 2004). The last two scenarios represented two simple climate change scenarios. The TI scenario represented a daily temperature increase of 2°C over the measured data with land cover and precipitation remaining the same as the base line. The PD scenario represented a daily precipitation decrease of 10% whenever a rainfall event occurred, while land cover and air temperature remained the same as the BL scenario. Similar grid subtraction calculations were performed in ArcView 3.3 for these application scenarios to examine the sensitivity of water table response to clear cutting and potential future climate changes.

RESULTS AND DISCUSSION

Model Calibration (1992–1993)

Water table data from nine individual wells (Figure 2) were used to calibrate the MIKE SHE model using data from 1992 to 1993. Model performance was qualitatively evaluated using graphical inspections. Trial and error procedures were used to adjust the parameters (Table 1) by evaluating R, ME, and E values (Table 2). These calibrated parameters remained the same during the 1994–1996 validation periods.

Correlations (R) between measurements and simulations for selected wells were high and ranged from 0.81 to 0.94. The ME values ranged from −0.34 m to 0.07 m and E values ranged from −0.87 to 0.77 (Table 2). These calibration results showed that MIKE SHE captured the temporal dynamics of water table variations at this flatwoods site (Figure 3A). During the wet year of 1992, water tables were very close to the ground surface and water was ponded on the wetlands over most of that year (Figure 3A). During the dry period (June–October) of 1993, water table was much lower than the ground surface and surface water was rarely evident, and the water table was closer to the ground surface in wetlands than in uplands. In general, the model underestimated water table depth in wetlands during wet periods but overestimated it in uplands during dry periods (Figure 3A). Discrepancies were most apparent during storm events after long drought periods (e.g., 1993).

Frequency analysis of the spatial discrepancies on October 29, 1992 indicated that overall water table differences between measurements and simulations

Table 1. Calibrated parameter values of MIKE SHE at the Florida wetland site.

Parameters	Parameter Values			
	Initial	Minimum	Maximum	Final
ET Coefficients				
C_{int}	0.05	0.05	0.8	0.5
C1	0.3	0.05	1	0.3
C2	0.2	0.05	0.5	0.2
C3	20	5	30	12
A_{root}	0.5	0.1	1	0.25
Horizontal Hydraulic Conductivity (m/s)	1.0×10^{-5}	1.0×10^{-6}	1.0×10^{-4}	3.6×10^{-5}
Vertical Hydraulic Conductivity (m/s)	1.0×10^{-5}	1.0×10^{-6}	1.0×10^{-4}	1.0×10^{-5}
Specific Yield	0.1	0.05	0.3	0.2

followed a normal distribution (Figure 4A). There were about 38% of differences within 0.1 m, 70% within 0.2 m, and 90% within 0.3 m. This normal distribution resulted from overestimation in the NW block and underestimation of water table depth in the SE block (Figure 4A). Topography might dictate this behavior because the SE block has lower elevations than the NW block (Figure 1).

Model Validation (1994–1996)

Similarly to model calibration, the model underestimated water depth in wetlands and overestimated water table depth in uplands during the 1994–1996 validation period (Figure 3B). Although the model predictions of water depth were systematically biased, there were high correlations between measured and simulated water table depths at the nine different locations, with R values ranging from 0.73 to 0.91. The ME values were within the range of −0.29 m to 0.15 m, and E values ranged from −1.23 to 0.69 (Table 2). Validation showed that MIKE SHE was able to capture water table dynamics over the three years, especially for uplands, as achieved during calibration. Water was ponded on the wetlands most of the time, except during the dry period (May–June) of 1994 (Figure 3B). On uplands, water table periodically reached the ground surface but did not pond due to the higher elevations (Figure 3B). Model underestimation of water table depth in wetlands was most pronounced during wet periods.

For the selected normal day during validation (March 11, 1994), MIKE SHE had a tendency to underestimate water table depth at uplands and in the SE block, and overestimate it at wetlands and in the NW block (as was the case during calibration). Overall, MIKE SHE tended to overestimate water table depths on 03/11/1994 at the landscape scale, and frequency analysis of the spatial differences indicated that 73% of the discrepancies were overestimation (Figure 4B). About 39% of the differences fell within 0.1 m, 68% within 0.2 m, and 85% within 0.3 m.

Key Factors Affecting the Discrepancies between Measurements and Simulations

Several factors may have contributed to the discrepancies between measured and simulated water table depths. First, there was little topographic variation across the study site. The topography

Table 2. MIKE SHE performances at nine testing wells at the Florida wetland site.

Wells	Calibration			Validation		
	R	ME (m)	E	R	ME (m)	E
K_Wet	0.90	0.07	0.74	0.79	0.12	0.03
K_Up	0.94	−0.18	0.68	0.89	−0.13	0.63
K_Up_Manual	0.86	−0.17	0.28	0.80	−0.15	0.28
N_Wet	0.89	0.07	0.73	0.84	0.15	−1.23
N_Up	0.87	−0.30	−0.55	0.91	−0.16	−0.14
N_Up_Manual	0.82	−0.26	−0.04	0.89	−0.07	0.56
C_Wet	0.81	0.07	0.47	0.73	0.00	0.37
C_Up	0.85	−0.34	−0.87	0.80	−0.29	−0.26
C_Up_Manual	0.91	0.01	0.77	0.84	0.00	0.69

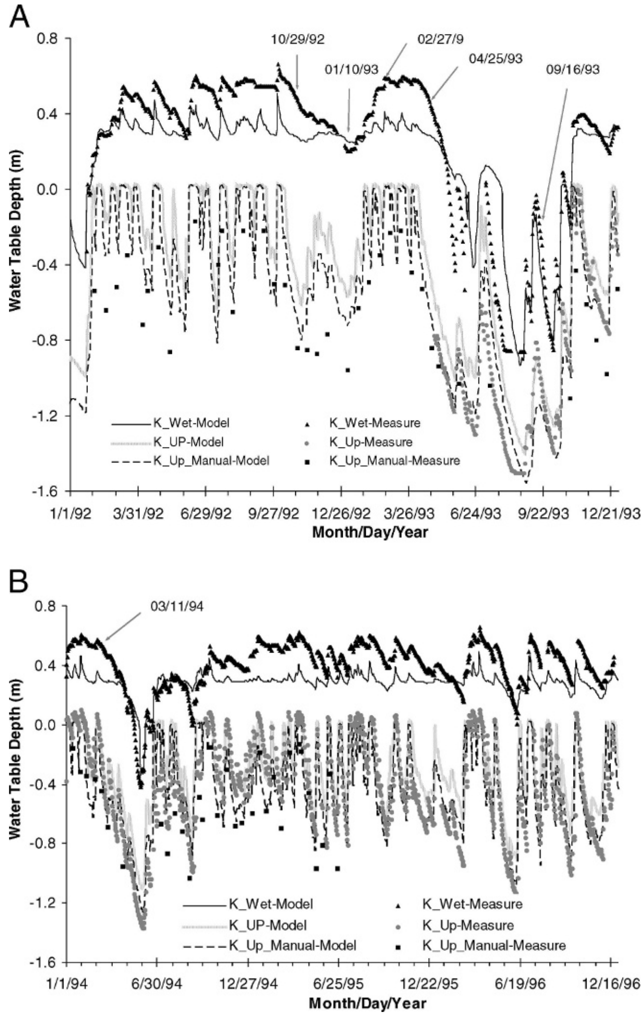

Figure 3. MIKE SHE model A) calibration and B) validation in the NW block during 1992–1993.

survey was conducted every 100 meters. Therefore, abrupt changes of surface topography at the wetland-upland interface might have not been recorded. Micro-topography effects were likely to be responsible for the large simulation errors (underestimation) in wetlands. The model performed relatively better when the water table was below the ground surface. Second, there was a lack of information about the spatial distribution of the confining soil layer depth (i.e., hydrologic restricting layer) and soil hydraulic parameters. Third, there were inadequacies of the model itself in describing surface-water and ground-water interactions at finer spatial scales (30 m in this case). More studies are needed to further identify the individual roles of these factors. Fourth, the ground-water table depth was influenced by the full hydrologic cycle. ET is a large flux in wetland ecosystem, thus any error in ET estimation could cause significant error in estimating soil water balances and thus water table depth. The ET procedure was not fully validated. Finally, there were challenges in calibrating a spatially distributed model. Nine wells were used to calibrate the model and three statistical criteria (R, ME, and E) were used to quantitatively evaluate the model. During the calibration process, parameter adjustments might improve one particular well's performance, but it could also deteriorate the simulations for another well. At the same well location, the improvement of R values might decrease the performances of ME and E values.

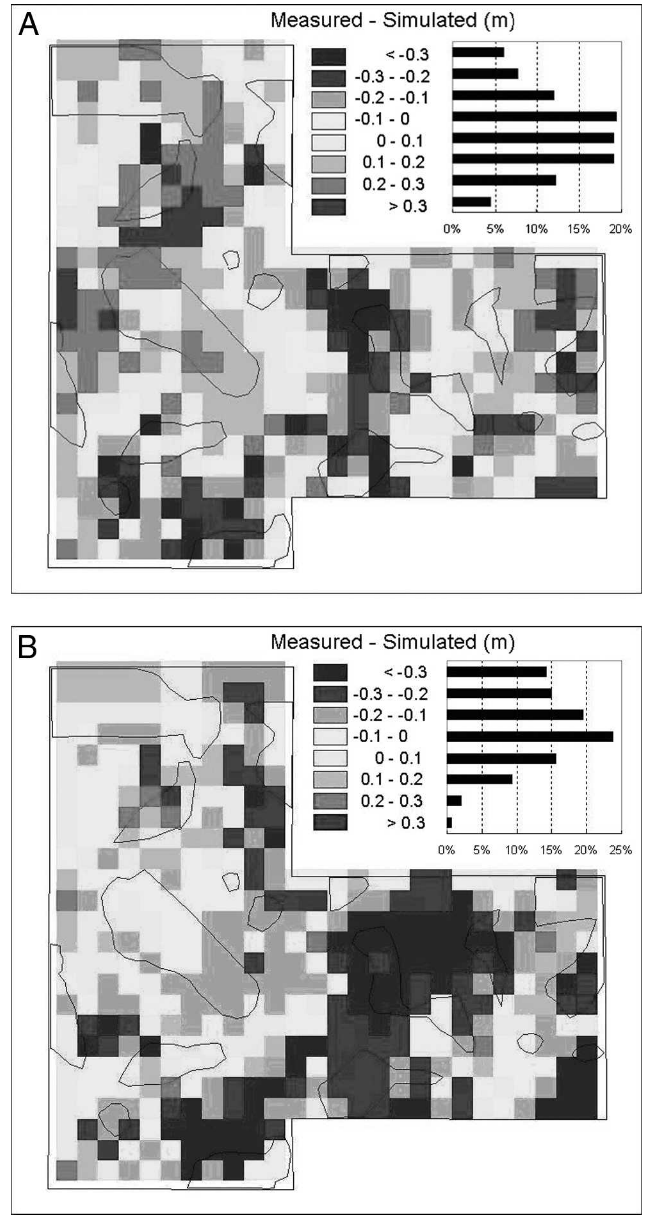

Figure 4. Spatial water table depth differences between measurements and simulations on A) 10-29-1992 and B) 03-11-1994 (30 m cell size; negative values indicate overprediction while positive values indicate under-prediction).

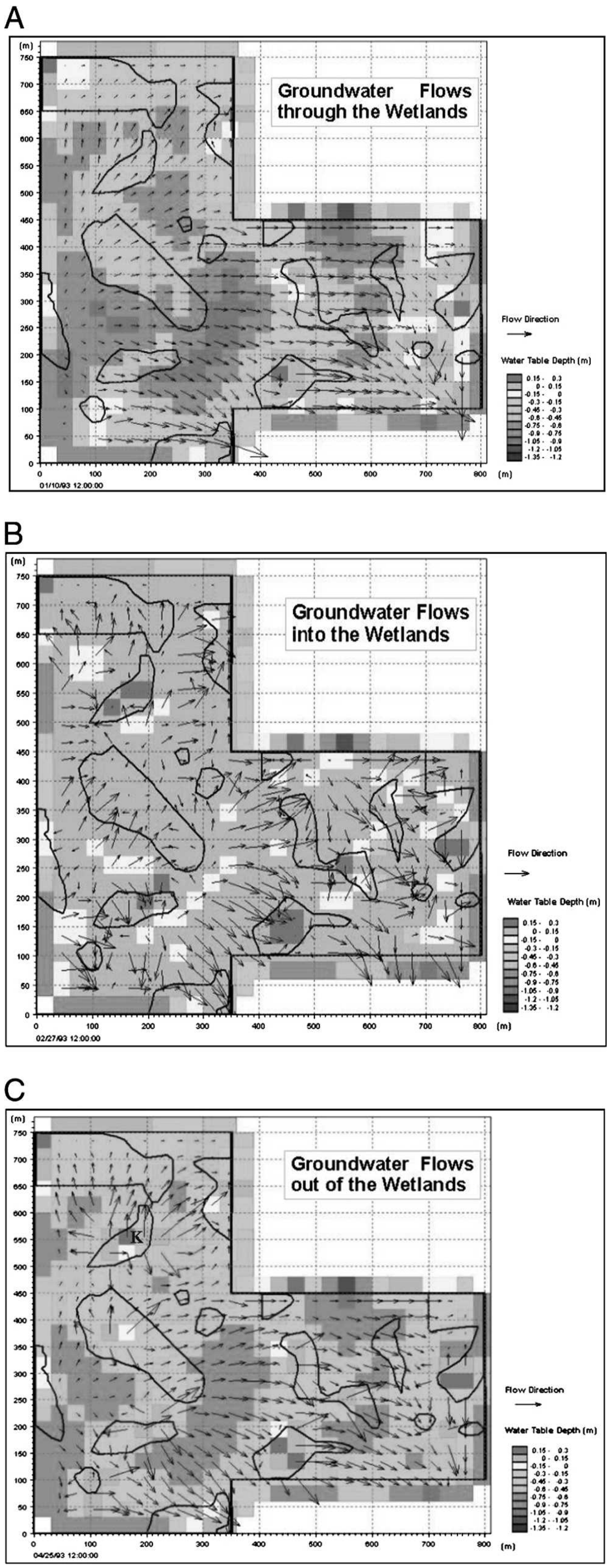

Figure 5. MIKE SHE simulated the flow pattern of ground water A) flow-through on 01-10-1993, B) flow-in on 02-27-193, and C) flow-out on 04-25-1993 (30 m cell size; water table depth was defined as the distance of the water table to the ground surface; it was negative or positive when the water table was below or above the ground surface).

Ground-water Flow Patterns

The field measurements showed three types of horizontal ground-water flow patterns, including flow-through, flow-in, and flow-out, of the flatwoods site (Crownover et al. 1995). MIKE SHE modeling identified and confirmed the three types of horizontal ground-water flow patterns: 1) flows through the wetlands (Figure 5A), 2) flows into the wetlands (Figure 5B), and 3) flows out of the wetlands (Figure 5C). Investigation of these general flow patterns further validated the MIKE SHE models capability to capture the hydrologic interactions between wetlands and uplands. Quantifying flow direction is important to determine the potential impacts of intensive pine management practices (e.g., fertilization) on wetland water quality. Although cypress wetlands are situated on low spots on the landscape, they are not completely flow or nutrient sinks (Crownover et al. 1995).

On 01-10-1993, a dry day, ground water generally flowed through the wetlands in response to the landscape topographic gradients (Figure 5A). Ground water was transmitted through the wetlands from the uphill side towards the downhill side. This flow pattern usually occurs in both wet and dry periods when localized water table fluctuation is stabilized. On 02-27-1993, a very wet day, ground water flowed from the surrounding uplands to the wetlands (Figure 5B). Wetlands were recharged and served as sinks of water from uplands. This flow pattern usually occurs under very wet conditions when the water table is high. On 04-25-1993, a day of transition from a wet to a dry condition, ground water flowed away from wetlands toward the surrounding uplands (Figure 5C); this was most obvious for K wetland. Wetlands served as the sources of water to the uplands, a pattern that usually occurs during the transition periods between wet and dry conditions.

The horizontal ground-water flow patterns were governed by hydraulic gradients across the landscape. During very wet periods after intense storms when water tables in uplands rose quickly and became higher than the wetlands, hydraulic heads in uplands were higher than those in the wetlands. Driven by the hydraulic gradient, water moved from uplands into wetlands (Figure 5B). This ‘focused

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flow' pattern was not common at this study site. Instead, water either flowed through the wetlands or flowed from wetlands toward the uplands (Crownover et al. 1995). Under most conditions, the landscape topographic gradient played a dominant role in controlling the hydraulic gradient. Thus, ground water flowed through the wetlands from the uphill side toward the downhill side (Figure 5A). When the water table dropped further during the transitions from wet to dry conditions, it dropped faster in uplands than in wetlands and in some rather flat locations resulted in a higher water table in wetlands than in uplands. This was most likely a result of the variable specific yield values of soils in wetlands and uplands. The specific yield could be as high as 1.0 when surface water presented while the specific yield of uplands was less than 0.2 when the water table was below ground. Thus, for the same amount of ET, the water table in uplands would drop much more than the wetlands would. Differential transpiration rates in wetlands and uplands might also contribute to this reversal flow phenomena (Crownover et al. 1995, Figure 5C). However, during dry periods when differential water storage in wetlands and uplands was small, the general landscape topographic gradient dominated groundwater movement and resulted in the flow-through pattern.

Clearly, the water balances within upland pine forests and cypress wetlands drive the spatial distribution of water table depth and thus the water flow directions. Also, surface topography and subsurface geology affect the flow direction and magnitude as suggested by Sun et al. (2006) on a Carolina bay system in South Carolina. The model simulations enabled us to examine the flow at a finer temporal and spatial scale. Furthermore, model simulations could help quantify the actual flow amount between wetlands and uplands, a function important to quantifying nutrient fluxes between a wetland and its supporting uplands.

Model Applications

Using the validated model, we evaluated the potential effects of three hypothetical scenarios on the ground-water table during 1992–1996. In terms of water table variations, modeling results suggested that forest clear-cutting and climate change would affect water table greatly during the dry periods (Figure 6). However, the impacts were not as great during wet periods. In the dry year (i.e., 1993), the water table elevation was much higher under the clear-cutting scenario than the base line. When temperature increased 2°C or precipitation decreased 10%, the water table dropped deeper than the base line scenario. This pattern could also be seen in the dry spring season of 1994.

Under the clear-cutting situation, total ET was reduced due to the lack of leaves, resulting in a higher water table than the base line. This was especially true during dry periods when tree roots can access soil water in a deeper depth for transpiration. This result agrees with many previous study results (Crownover et al. 1995, Sun et al. 2000, Bliss and Comerford 2002), which provides further support for our simulation results. However, the effect of clear-cutting on shallow ground water is short-term and will gradually subside as trees recover (Sun et al. 2001). An increase in air temperature by 2°C increased PET, and thus increased water loss. An increase in water loss resulted in a further drop of the water table level. A 10% precipitation decrease would decrease soil water recharge, and therefore lower the water table level. During wet periods, the water table was near or reached the ground surface. Water was sufficient for plant use and satisfied the PET demand most of the time, so water table level change due to forest management and climate change were minimal. However, during the dry periods when the water table was well below the ground surface, impacts were stronger, which suggests that the water table is more sensitive to climate change during dry periods.

Impacts of clear-cutting and climate change on ground-water table can be examined at the landscape scale. We used the date 09-16-1993 to demonstrate the special effects of forest management and climate change (Figure 7). Effects from the three hypothetical scenarios had water table variations in a range of 20–40 cm on 09-16-1993. Spatial inspections suggested that the water table drop resulted from a 2°C temperature increase was slightly lower than that from a 10% precipitation decrease. Similar to the findings from point-level comparisons (Figure 4), water table in wetlands were more responsive to forest removal and climate change than surrounding uplands.

CONCLUSIONS

This study showed that MIKE SHE adequately described the general hydrologic patterns of a complex cypress wetland – pine upland ecosystem. MIKE SHE identified three horizontal groundwater flow patterns at this study site. This simulation study confirmed field observations about the interactions between wetland surface water and upland ground water on a typical flatwoods

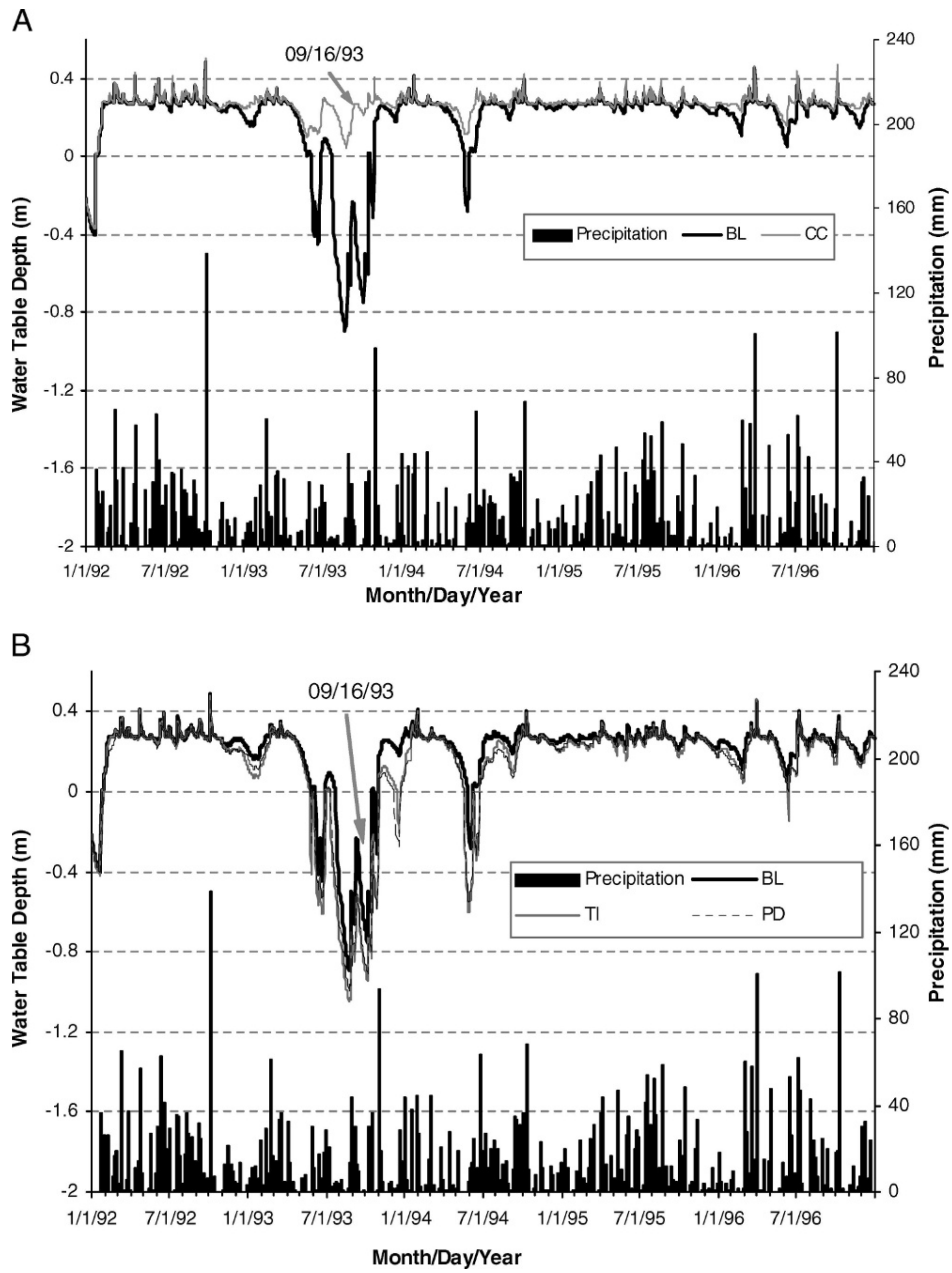

Figure 6. Impacts of A) clearcut and B) climate change on water table at the automatic well (C_Wet) in the SW block during 1992–1996 (BL - base line; CC - clearcut; TI - 2°C temperature increase; PD - 10% precipitation decrease. For the CC case, a 30 percent reduction of potential ET was assumed (Grace and Skaggs 2006, G. Sun Unpublished data)).

landscape. MIKE SHE had the advantages of simulating both temporal and spatial flow dynamics at the landscape scale.

Simulations of the four hypothetical scenarios indicated that forest removal and climate change can have great impacts on the ground-water table dynamics during the dry periods while the impacts might be minimal during wet periods (i.e., high water table conditions). At the landscape scale, depressional wetlands that receive surface water and ground water from surrounding uplands are most likely sensitive to land disturbances and climate change.

Wetland ecosystem structure and functions are controlled by the water table dynamics that are often influenced by wetland configuration and associated upland hydrology at the watershed scale. This study represents the first attempt to validate a distributed wetland hydrologic model using measured water table depth at a landscape scale. Although the MIKE SHE model described the wetland-upland

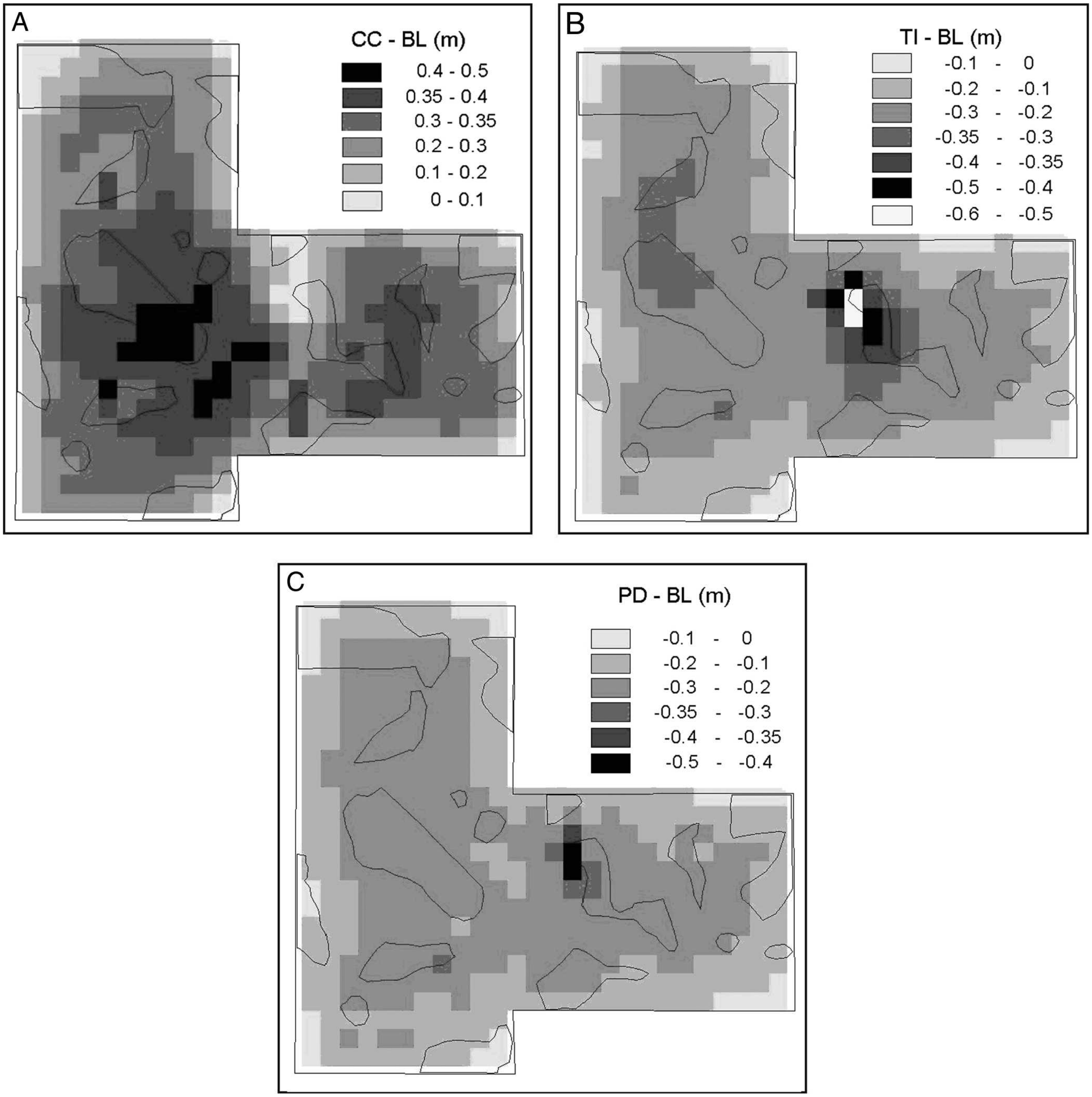

Figure 7. Model simulation (30 m cell size) indicated that on 09-16-1993 A) water table rose as a result of clearcut (CC - BL was defined as the water table depth in CC scenario - the water table depth in BL scenario), B) water table dropped due to 2°C temperature increase (TI - BL was defined as the water table depth in TI scenario - the water table depth in BL scenario), and C) water table dropped due to 10% precipitation decrease (PD - BL was defined as the water table depth in PD scenario - the water table depth in BL scenario).

systems adequately, further studies are needed to test how the model simulates other major fluxes in wetlands, such as ET to reduce prediction errors. Improved data quality on surface elevation may enhance hydrologic predictions. Future studies should also use dynamic climate change scenarios derived from global circulation models with consideration of vegetation feedbacks on the ET processes. Modeling results from the MIKE SHE model could further be integrated with biogeochemical models to fully take advantage of the hydrologic information provided.

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