THE MISSING COMPONENT IN FOREST HYDROLOGY MODELS

Sydney T. Bacchus

AUTHOR: Institute of Ecology, University of Georgia, Athens, Georgia 30602; e-mail: sbacchus@arches.uga.edu
REFERENCE: Proceedings of the 1999 Georgia Water Resources Conference, held March 30-31, 1999, at the University of Georgia. Kathryn J. Hatcher, editor, Institute of Ecology, University of Georgia, Athens, Georgia.

Abstract: "FLATWOODS", a forest hydrology model recently developed for predicting hydrologic impacts of different forest management practices in the southern Coastal Plain (SCP), provides advantages over alternative models. However, the "FLATWOODS" model was developed and tested using slash pine plantations, and differences in interception/throughfall and evapotranspiration for natural flatwoods stands vs. pine plantations are not addressed by the model. More significantly, "FLATWOODS" does not account for the influence of anthropogenic alterations of hydrology due to municipal groundwater withdrawals in the vicinity of the site where the model was developed. Hydrologic perturbations are evident in many of the depressional, pondcypress (*Taxodium ascendens*) wetlands on the site, which exhibit signs of subsidence and premature decline typically associated with regional groundwater withdrawals in similar areas of the SCP. Increased transmissivity of the karst aquifer reported at the nearby municipal wellfield since pumping was initiated is evidence of the dynamic nature of karst aquifers subjected to groundwater mining. This provides additional support that the hydrology at the site where the model was developed may have been altered significantly by groundwater mining prior to data collection for development of the "FLATWOODS" model. These factors limit the predictive ability of the "FLATWOODS" model for natural pine flatwoods stands, and for pine plantation stands where groundwater mining does not occur. However, an opportunity exists to evaluate some aspects of the influence that groundwater mining has on this site by incorporating additional data and refining the model.

INTRODUCTION

Recently, a new distributed parameter model ("FLATWOODS") was developed for predicting hydrologic impacts of different forest management practices in the Coastal Plain (Sun et al., 1998a; 1998b). In theory, this model offers distinct advantages over other, lumped parameter model options available for forested areas of the SCP, a significant portion of which was natural pine flatwoods. Unfortunately, the conditions under which this model was developed place several limitations on use of the model to predict hydrologic responses of harvesting on other sites. The objectives of this paper are to provide a brief description of factors that are not addressed in the "FLATWOODS" model, and conditions at the site of model development, which will influence modeling of forest hydrology in the SCP.

DISCUSSION

Stand Characteristics

The sites of model development and model application, Gator National Forest (GNF) and Bradford Forest (BF) were described by Sun et al. (1998b) as "two typical flatwoods sites in north central Florida." The authors may have intended to indicate that the soils supporting the pine stands are typical pine flatwoods soils. Both sites historically were typical pine flatwoods, but were converted to pine plantations years prior to development and application of the "FLATWOODS" model.

In pine plantations, the density of the planted pines is considerably greater than in natural pine flatwoods stands. This results in an increase in water loss from a pine plantation stand compared to a natural pine flatwoods, due to net increase in transpiration and canopy interception/evaporation associated with greater stand density. Increases in transpiration also may be associated with species conversion if a natural flatwoods stand of relatively slowly growing longleaf pine (*Pinus palustris*) is replaced by more rapidly growing loblolly pine (*P. taeda*) or slash pine (*P. elliottii*), as was the case on these sites. A more detailed discussion of potential hydrologic changes associated with conversions of natural pine flatwoods to pine plantations in the SCP is provided by Bacchus (1995). Because of these stand influences on the water budget of a site, the "land use type" (= cover type) category of "Watershed Configuration" inputs specified to run the "FLATWOODS" model (Sun et al., 1998a) should include separate categories of "natural pine flatwoods" and "pine plantations", rather than a single general "pine upland" category. Consequently, the conclusion by Sun et al. (1998a) that the "FLATWOODS" forest hydrological simulation model provides an alternate tool to study the hydrology of pine flatwoods ecosystems is without basis, since the sites where the model was developed and applied were planted pine plantations, not pine flatwoods ecosystems.

Water loss due to canopy interception/ evaporation also varies within a given pine plantation with the age of the trees. For example, Swank et al. (1972) evaluated interception loss in a loblolly pine plantation of 5, 10, 20 and 30 years of age in South Carolina, and found that interception was lowest in the oldest age class (15%) and highest in the 10 year old stand (27%). The age of the stand used to develop the "FLATWOODS" model was not specified by Sun et al. (1998a; 1998b), but was comparable to the oldest stand evaluated by Swank et al. (Katherine Ewel, pers. comm.). In addition, transpiration may decrease significantly in older stands, as growth slows and the canopy thins. Consequently, if younger stands are harvested, greater changes in hydrology may be expected than those observed on the GNF site where the "FLATWOODS" model was developed. The "Vegetation Parameters" included in the list of model inputs includes changes in leaf area index (LAI) with Julian time (Sun et al., 1998a), which accounts only for seasonal changes in the canopy of a given age class. The influence of age class is not addressed in model inputs, but will influence model outputs of interception, evaporation, transpiration, total surface runoff (overland flow), and percolation.

For the mature slash pine trees, maximum LAI and transpiration rate were assumed (Sun et al., 1998a). If slash pine stands are similar to the loblolly pine stands evaluated by Swank et al. (1972), peak canopy conditions occurred approximately 20 years prior to development of the "FLATWOODS" model. Consequently, LAI and transpiration, in addition to interception during the time of model development may have been considerably less, and throughfall considerably greater than in younger stands.

Cypress stands also were assumed to be in the mature stage, with maximum LAI (Sun et al., 1998a). Although the trees were in a mature stage, many were exhibiting signs of premature decline, including sparse canopy. Canopy reductions can result from fewer leaves, smaller leaves, or both, leading to abnormally lower LAI and net transpiration. As noted by the authors, actual transpiration (AT) involves both physical and physiological processes, and is the most difficult component to model (Sun et al., 1998a). Prolonged stress/premature decline of the pondcypress is expected to influence both AT and LAI, although these impacts are not addressed by the model. Transpiration is treated as a physical component input, ET, under the "Soil Parameters" category. The evaporation aspect of ET also may be influenced by the physiological state of the pondcypress. Field data from the GNF site suggested that floating pan evaporation under the cypress wetlands canopy was 30% of standard pan evaporation (Liu, 1996). The floating pan evaporation may have been even less under the full canopy of unstressed pondcypress.

In the absence of additional complications, the "FLATWOODS" model could be applied to similar-aged stands of slash pine plantations in the SCP without modifications, or modified for application to pine plantations of other age classes and species, or possibly to natural pine flatwoods in the SCP. Unfortunately, a more significant problem must be addressed before application of this model.

Prior Hydrologic Perturbations

Evapotranspiration (ET) is described as the most important component of pine flatwoods water balance (Sun et al., 1998a). This may be the case for pine flatwoods and pine plantations in areas of the SCP where groundwater mining is not occurring. However, at sites in proximity to groundwater mining locations, induced recharge may be the most important water balance component. The GNF site, selected for development of the model, is in close proximity to the Murphree wellfield. This wellfield supplies water from the Floridan aquifer to Gainesville, Florida for municipal use. The Floridan aquifer is a regional karst groundwater system extending from south Florida throughout southern Georgia, South Carolina, Alabama, and Mississippi (Miller, 1992). This regional system has been a primary source of ground water for industrial, municipal and agricultural use for approximately 100 years, resulting in both short-term and long-term perturbations of the overlying surficial aquifer and surface water resources. Impacts are most severe in areas with depressional pondcypress wetlands and surrounding pine stands characteristic of the GNF site where the "FLATWOODS" model was developed. However, some depressional wetlands within a given area may exhibit delayed responses to groundwater mining due to differences in preferential flow, subsidence and collapse. A summary of impacts associated with groundwater mining is provided by Bacchus (1998).

The approximate UTM coordinates for the Murphree wellfield are 3287000mN and 374000mE, while the approximate UTM coordinates for the GNF site are 3296000mN and 380000mE. The wellfield consists of 11 wells, 61 cm (24 in) in diameter, constructed in an L-shaped configuration. Five wells are oriented north/south, with the remaining wells oriented east/west. The wells extend approximately 90-180 m (275-545 ft) deep, into the Avon Park formation. The total production capacity of the 11 wells is 57.8 million gallons per day (mgd). Pumping from the municipal wells near the GNF site began in 1968 and 1969 for eight wells, with the final three wells coming on-line in 1990 (Gainesville Regional Utilities, 1991).

Collection of groundwater data for development of the "FLATWOODS" model was initiated approximately 25 years after initiation of withdrawals from the Murphree wellfield. Consequently, significant alteration of the natural hydroperiod of the former pine flatwoods site may have occurred years prior to the collection of data for the "FLATWOODS" model. Statements by Sun et al. (1998b) that the hydrology "varies dramatically from year to year" and that "evaporation from the sandy soils was usually limited as the water table was below the 35 cm depth" suggest that induced recharge is occurring at the site where the model was developed, and that fluctuations in the surficial aquifer were being governed by groundwater pumping. Additional support is provided by observations of little overland flow at the GNF site by Sun et al. (1998a), and "runoff in the low range compared to that in other regions" after simulating clear cutting of a pine plantation using the "FLATWOODS" model (Sun et al., 1998b). Considerable overland flow has been observed in pine flatwoods located throughout the state of Florida, but not associated with major supply wells, following rainfall events of various magnitudes and durations (Bacchus, unpub. data). Furthermore, the lack of significant difference between the Control and two Treatment groups regarding effects of clear cutting on the water table, overland flow and ET (Sun et al., 1998b) may have been due to the over-riding influence of induced recharge from municipal wellfield withdrawals.

These findings are consistent with the typical symptoms of hydroperiod perturbation (e.g., subsidence, premature decline of pondcypress) observed in many of the pondcypress wetlands on the GNF site (Bacchus, unpub. data), providing additional support for the hypothesis that significant alteration of the hydroperiod has occurred. Without additional information it is difficult to determine how much of the perturbations is due to the municipal withdrawals and how much, if any, is due to hydroperiod perturbations from the conversion of the former pine flatwoods stand to a pine plantation stand.

Sun et al. (1998a) confirm that the complex geologic formation of flatwoods has resulted in the poor documentation and understanding of the preferential water pathway under different management conditions. The geologic complexity of the interspersed depressional wetlands in the SCP is even greater, and includes more direct connection with the underlying karst aquifer than the surrounding uplands. Consequently, a more extensive network of observation wells is required in the depressional wetlands at the GNF site to characterize the interaction between the local watershed and the underlying Floridan aquifer. The lack of understanding of preferential flow resulted in the typical description of a watershed as a "closed system" in which the boundary conditions at "watershed ridges" can be set as a no-flow boundary in the discussion of groundwater flow by Sun et al. (1998a). In areas of former or existing pine flatwoods in the SCP, "watershed ridges" are difficult to identify because of the broad expanses with limited topographic relief. At the GNF site where the model was developed, a change in elevation of only 3.4 m occurs over a distance of 800 m (Sun et al., 1998a). A more significant problem is the failure to recognize induced recharge as negating the concept of a closed watershed system. For example, induced recharge may convert a typical low flow (seepage) boundary between the surficial aquifer and underlying Floridan aquifer to a significant downward flow boundary. In cases of subsidence or collapse, flow no longer will adhere to Darcy's Law, as incorporated in the "FLATWOODS" model (Sun et al., 1998a). This may occur even if the location of withdrawals is within another watershed.

The conclusion by Sun et al. (1998b) that shallow groundwater levels are controlled by both the precipitation input and the evaporation output ignores the influence of induced recharge, which is capable of over-riding both referenced input and output. Induced recharge at the GNF site due groundwater withdrawals from the municipal wellfield may be the primary factor responsible for the inability of the model to predict peaks of overland flow in the "control" watershed located in the BF site, in addition to producing the low Pearson Coefficients (0.61 and 0.62) for the wet years tested by Sun et al. (1998a). Until additional work has been done to evaluate the influence of groundwater withdrawals at the GNF site and the influence of cover-type conversion, assumptions cannot be made that the "FLATWOODS" model represents typical responses in natural pine flatwoods stands, or in pine plantations planted on sites of former pine flatwoods that are not influenced by groundwater withdrawals.

Groundwater flow is listed as one of four major submodels (Sun et al., 1998a; 1998b); however, model illustrations do not include induced recharge prompted by municipal groundwater mining (Sun et al., 1998a; 1998b). The model illustrations also fail to include an upward groundwater leakage component. Upward leakage typically occurs in the Floridan aquifer in areas where groundwater mining does not occur and the potentiometric surface is greater than the level of the overlying surficial aquifer. Upward leakage also occurs in areas of groundwater mining when pumping is reduced. This reversal of upward leakage due to induced recharge and concomitant disturbance of transpiration by affected trees may have been a predominant factor in the reported unsuitability of energy-balance Bowen ratio and eddy correlation methods in west-central Florida (Bidlake et al., 1993), where extensive groundwater mining has resulted in the premature decline and death of many trees.

CONCLUSIONS

The "FLATWOODS" model provides distinct advantages over existing, lumped parameter models for pine flatwoods in the SCP; however, the stated goals of the model cannot be achieved. Sun et al. (1998a) indicate that the model was "developed and validated for pine flatwoods [sic] to: 1) predict spatial and temporal hydrologic effects of forest management practices; 2) account for hydrologic heterogeneity and continuity of wetland/upland ecosystems and environmental variables; and 3) provide a tool for forest water management and hydrologic research". They further conclude that the "FLATWOODS" model may be used for predicting hydrologic impacts in the coastal regions. Sun et al. (1998b) suggest that the model can be used to: 1) extrapolate/export research results to unguaged areas; 2) explore the details of hydrologic processes within a watershed; 3) predict potential impacts of various management scenarios; and 4) synthesize data.

Differences in water budget components between natural pine flatwoods and planted pine plantation stands, in addition to differences within a planted stand as the trees age, restrict application of the model to slash pine plantations with trees of similar age, in the absence of modifications to account for these differences. A more significant factor is evidence that the hydrology at the site of model development has been altered and may be influenced by municipal groundwater withdrawals in proximity to GNF. Until the influence of induced recharge due to groundwater mining is accounted for, as the missing hydrologic component, the influence of clear cutting treatments in the GNF pine plantation cannot determined and the potential advantages of this model cannot be realized. However, the GNF site provides an excellent opportunity to evaluate some aspects of the influence that groundwater mining has on this site by incorporating additional data and refining the model.

LITERATURE CITED

Bacchus, S. T. 1995. Potential for reduced infiltration and recharge on a local scale following cover type conversion in the southeastern Coastal Plain. pp. 207-210 *in:* K. J. Hatcher (ed.) Proceedings of the 1995 Georgia Water Resources Conference, held April 11 and 12, 1995, at The University of Georgia, Athens, Georgia.

Bacchus, S. T. 1998. Determining sustainable yield in the southeastern coastal plain: A need for new approaches. pp. 503-519 *in:* J. W. Borchers (ed.) Land Subsidence Case Studies and Current Research: Proceedings of the Dr. Joseph F. Poland Symposium, October 2-8, 1995, Sacramento, California. Association of Engineering Geologists Special Publication No. 8.

Bidlake, W. R., W. M. Woodham, and M. A. Lopez. 1993. Evapotranspiration from Areas of Native Vegetation in West-Central Florida. U. S. Geological Survey Open-File Report 93-415. 35 pp.

Gainesville Regional Utilities. 1991. Murphree Wellfield Pumping Projections. Submitted to the St. Johns River Water Management District for the 1991 Consumptive Use Permit Application.

Lui, S. 1996. Evapotranspiration from Cypress (*Taxodium ascendens*) Wetlands and Slash Pine (*Pinus elliottii*) Uplands in North-Central Florida. Ph. D. Dissertation, University of Florida, Gainesville, FL. 258 pp.

Miller, J. A. 1992. Summary of the Hydrology of the southeastern Coastal Plain Aquifer System in Mississippi, Alabama, Georgia, and South Carolina. Regional Aquifer-System Analysis - Southeastern Coastal Plain, USGS Professional Paper 1410-A. 38 pp. + maps

Sun, G., H. Riekerk, and N. B. Comerford. 1998a. Modeling the forest hydrology of wetland-upland ecosystems in Florida. Journal of the American Water Resources Association 34(4):827-841.

Sun, G., H. Riekerk, and N. B. Comerford. 1998b. Modeling the hydrologic impacts of forest harvesting on Florida flatwoods. Journal of the American Water Resources Association 34(4):843-854.

Swank, W. T., N. B. Goebel, and J. D. Helvey. 1972. Interception loss in forest stands. pp. 1-9 *in:* Forest Fertilization Theory and Practice. TVA Nat. Fertilizer Development Center, Muscle Shoals, AL.