GIS-BASED COUPLING OF GLEAMS AND REMM HYDROLOGY: II. FIELD TEST RESULTS

M. A. Tucker, D. L. Thomas, D. D. Bosch, G. Vellidis

ABSTRACT. *Agricultural fields border riparian areas in many locations. These riparian areas provide important filtering capabilities for agricultural chemicals and sediment leaving upland agricultural areas. Several models have been developed for upland agricultural areas and for riparian zones. The need to integrate such models through a flexible structure which represents the field conditions is highly desirable. Since water is the primary mechanism for pollutant transport, the system must be capable of managing both surface and subsurface water movement. The hydrology components of the upland agriculturally oriented water quality model, GLEAMS, and the riparian ecosystem management model, REMM, were coupled through a GIS to allow evaluation of agricultural and forest management impacts on water movement for typical field situations in the southeastern Coastal Plain. Programs and subroutines were developed to allow delineation of field areas, identification and maintenance of data based on the field map, and incorporation of data to the input data format for each model. The model system was capable of representing the shallow groundwater levels from forest management practices of clear-cut, thinned, and mature forests in field comparisons with measured values from the Gibbs Research Farm near Tifton, Georgia, for 27 months of comparison data between 1992 and 1994. Simulated monthly average shallow groundwater levels were within 0.14, 0.08, and 0.25 m of measured groundwater levels for the clear-cut, thinned, and mature forest treatments, respectively. Correlation results for the same treatments indicated at least an* r^2 *of 0.78 for all simulated versus measured monthly shallow ground water results. The model system did not respond as well in representing field conditions on total monthly runoff. Average monthly differences in total simulated runoff were 0.73, 1.19, and 0.48 cm lower (highly significantly) than measured results for the clear-cut, thinned, and mature forest management treatments from the Gibbs Farm site, respectively. No correlation was indicated between simulated and measured total runoff. The model system did, however, indicate the runoff trends expected due to changes in forest management. As the number of trees and canopy increased, runoff decreased. The model system has the potential of providing a cost effective method of incorporating multiple model characteristics into management practice evaluations.*

Keywords. *Water quality, Models.*

The development of any agricultural non-point source water quality model should include a comparison with field data to evaluate the model's representation of field conditions. In all cases, parameter input values should be consistent with the field characteristics. For a model "system" (combination of more than one model) to reflect reality, some slight variations in this concept can be used, IF the models in the system remain intact. All previous attempts to validate the individual models can be associated to at least a part of the system, if the model is used in a manner consistent with previous validation tests. Obviously, a combined model system will have some relationships to calculate the movement of water from one model to the other (which may not have been validated). Such is the case when considering "validation" of the GLEAMS/REMM model system which includes GLEAMS (Groundwater Loading Effects of Agricultural Management Systems, Leonard et al., 1987), a widely used and verified model, and REMM (Riparian Ecosystem Management Model, Lowrance et al., 2000) which has experienced limited validation to date.

An integrated model system which is based within a Geographical Information System (GIS) was developed using a cascaded approach with the GLEAMS and REMM non-point source water quality models (Tucker, 1998; Tucker et al., 2000). In this particular development, only the hydrology components of the models were integrated. The purpose of this development was to create a system which represents a typical agricultural landscape in the southeastern Coastal Plain of the United States and many other areas. An agricultural field bordered by a woodland area adjacent to a stream (or intermittent stream), called a riparian area, is common throughout the region. Unfortunately, the ability to track chemical (nutrients and

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pesticides) movement as it travels from the agricultural field and through a riparian area in both surface and subsurface modes is not easy to simulate. For purposes of implementing the overall best management practices for a particular situation, the size of each riparian area (grass, managed forest, virgin forest) and alternative agricultural and forest management practices should be simulated in combination (fig. 1).

The idea to use both these models in a cascaded format is not unique and was an intention from the inception of REMM. Other researchers are interested in that functional ability as well. Gerwig et al. (1998) evaluated the GLEAMS and REMM (pre-release version) models for simulating the movement of nutrients from a spray field and through a riparian forest in the South Carolina Coastal Plain. Their preliminary simulation results, from two different application rates of 560 and 1000 kg N/ha, indicate that nitrogen transport through the system was adequately simulated by both models. The REMM-simulated NO_3-N leachate concentrations were underestimated for the lower nutrient application test, and REMM was not as responsive to changing conditions as were field measured results. The partitioning of water from the subsurface flow in GLEAMS to REMM was a concern in that analysis.

Both the GLEAMS and REMM models have been validated for southeastern U.S. and Coastal Plain conditions. The GLEAMS model surface hydrology simulation uses technology from the CREAMS model (Knisel et al., 1980) which encompasses an extremely large data base of validation tests for this region and beyond. Leonard et al. (1987) illustrate several validation tests in the first documentation paper for GLEAMS. Knisel et al. (1991) also provide validation results for GLEAMS with field data from the Georgia Coastal Plain. Ma et al. (1998) evaluated GLEAMS performance for runoff prediction from a Coastal plain loamy sand and found GLEAMS predicted runoff was within 10% of the measured results. Reyes and Cecil (1997) indicated that GLEAMS underpredicted runoff by an average 34% under a tillage test in the Coastal Plain of North Carolina indicating a potential need for improved parameter values for different tillage systems. Overall, simulation results were consistent with measured values.

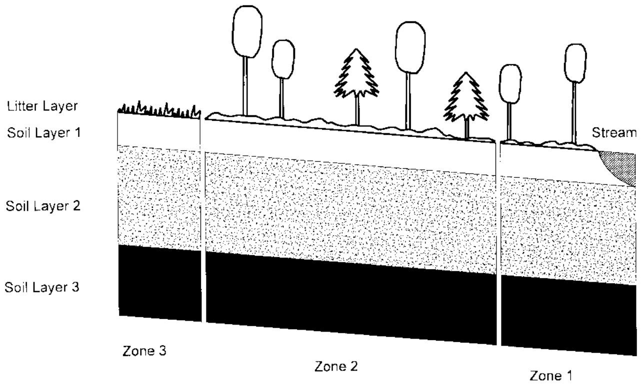

Figure 1–Illustration of a riparian forest buffer between an agricultural field and a stream as defined in REMM.

For REMM, Inamdar et al. (1999) validated the model system with field measured data from a Coastal Plain soil in south Georgia. The model estimated shallow water tables within 7 cm of measured values in Zones 1 and 2 on average. Model result fluctuations were consistent with observed variations in the water table. Simulated runoff results were within one standard deviation of the measured runoff.

Each of the above validation tests do not include the combined function of GLEAMS and REMM in a cascaded format. The development of such a system and performance in simulating the response of water as it moves from an upland agricultural area and through a riparian zone is required before a combined system can be ruled a useful and representative approach. By building the model interface within a GIS, the potential exists to allow changes in model parameters and analysis of the impacts of those changes on a spatial basis more readily than with the individual models. In addition, parameter values which can be transported across different data sets (such as weather and soil characteristics) may be more accessible for simulation tests at future dates. This model validation builds on the concepts indicated by Tucker (1998) and Tucker et al. (2000). For additional information regarding development of the integrated system and the relationships used to integrate the models and data sets, the reader is referred to those references.

OBJECTIVES

The objectives of this article are to evaluate the capabilities of the REMM and GLEAMS combined system in simulating field conditions. The primary objective is to compare simulation results to measured results for a Coastal Plain riparian area. The parameters of primary concern are surface runoff and shallow groundwater levels. Forest management conditions within the riparian area of mature, thinned, and clear-cut are included in the comparisons.

METHODS

The GLEAMS model used was the software version available in 1993 (Knisel et al., 1993). The REMM model system was the hydrology component of the preliminary release version (Lowrance et al., 2000). The GIS package used was SPANS (SPatial ANalysis System) which uses a data modeling format with variable raster cell sizes (Intera Tydac, 1992). For additional details of the models, equations, and the GIS system the reader is referred to Tucker (1998) and Tucker et al. (2000).

The site for the implementation of the project is located in Tift County, Georgia, on the Coastal Plain Experiment Station (CPES) Gibbs Research Farm. The site included a 1.8 ha (4.4 acre) upland agricultural field adjacent to a riparian area (fig. 2). The riparian area bordering the field had previously been partitioned for three different management practices (clear-cut, thinned, and mature forests) in November 1992 (Lowrance et al., 1997). The soils at the site are a typical Tifton loamy sand (average 1.5% slope, *Plinthic, Kandiudults*; fine-loamy, siliceous, thermic) in the upland area grading into an Alapaha loamy sand (average 2.5% slope, *Arenic Plinthic Paleaquults*; fine-loamy siliceous, thermic) in the riparian area. The

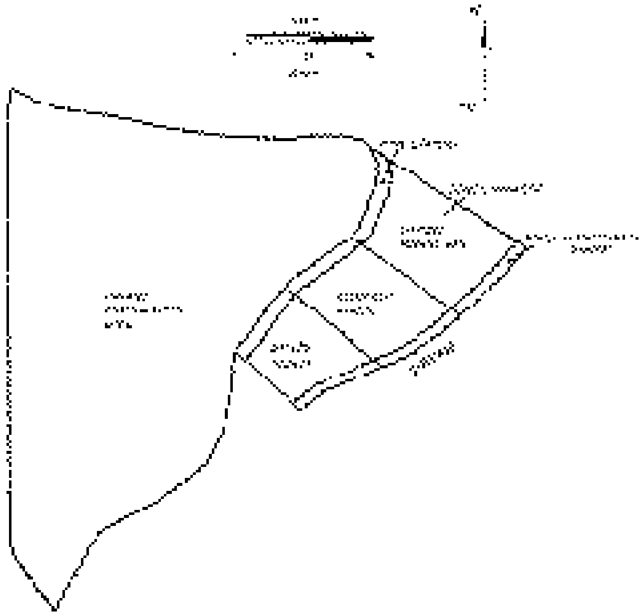

Figure 2–Riparian and upland area study site at the Gibbs Research Farm near Tifton, Georgia.

field site has been described extensively in previous work, but typical water movement is via surface runoff and lateral subsurface flow above a confining layer which creates a shallow groundwater table (Bosch et al., 1996).

Instrumentation was installed in 1992 for monitoring surface runoff and shallow subsurface water levels between and through the typical three zones of a managed riparian area (Bosch et al., 1996; Sheridan et al., 1999). Surface runoff was monitored using 30.5-cm-wide "dustpan" collectors with either 10% or 1% partitioning of the surface inflow (Sheridan et al., 1996). Other elements monitored through grab sampling included nutrient and pesticide concentrations in surface, subsurface, and stream water (Lowrance et al., 1997).

Tillage and cropping histories of the upland agricultural area were supplied by the U.S. Department of Agriculture, Agricultural Research Service (USDA-ARS) Southeast Watershed Research Laboratory (SEWRL). The history covers the 1992 through 1994 cropping seasons from 3/12/92 to 8/24/94. Conventional tillage practices were used in all three growing seasons associated with field corn production (Bosch et al., 1996). Soil preparation for planting began with shallow tillage using a disk harrow to chop winter residue. Deep tillage included use of a moldboard plow for deep turning of soil and a bedder for creating seed beds. A rototiller was used to level the seed beds and to incorporate pre-emergence herbicides. During the growing season, a row crop cultivator was used to mechanically remove weeds and to apply ammonium nitrate fertilizer. After harvest, crop residue was mowed then disk harrowed.

Riparian forest management in late 1992 included removal of all trees from the clear-cut site, selective removal of trees from the thinned area and no tree removal from the mature forest section. The clear-cut and thinned sections experienced rapid regrowth of herbaceous vegetation, which is a typical response upon removal of the tree canopy (Lowrance et al., 1997; Bosch et al., 1996). The clear-cut section was replanted to pine trees a few weeks after harvest, but was not expected to provide significant canopy for several years.

PARAMETERS FOR THE TEST SITE

The field and riparian area coverages were acquired from the SEWRL in Tifton, Georgia. The initial step in the data management process was to convert the survey data into a GIS format. The SPANS GIS software package provided routines and techniques to convert that data. The conversion process also included some manual manipulation to remove excess points, and to make sure all vectors were connected.

Next, a process termed point-in-polygon was used to provide a locational reference for attributes of each polygon. A single point was placed within each map polygon, i.e., field and riparian zone. To these points were attached a unique identifying number for each polygon. Also, level numbers were attached which identified each polygon as a field or one of the three zones within each riparian area. After completing the changes and additions made to the coverage, the polygon data were exported as a vector file which is the required input file format for the GIS. This file lists the geographical coordinates of the arc vertices (line segment endpoints) and the points of the point-in-polygon process.

Before importing the coverage vector file into the GIS, a study area was opened and setup within the GIS environment. This entailed establishing a projection for the study area. The Universal Transverse Mercator (UTM) projection, Zone 17, was used with the 1866 Clarke ellipsoid. Next, the extents for the study area were set. The extents define the size of the window in the projection plane that encompasses the study area. The GIS software used the coordinates of the vector file to establish the extents by determining the lower most lefthand and upper most righthand vertices in the vector file and setting the study area window accordingly.

After establishing a projection and setting the study area extents, the coverage vector file was imported into the GIS. Upon importing the vector file, which also contains the point coordinates and attributes, a separate file was created by the GIS to accommodate the point data. The newly created point file was later imported into the study area separately from the vector file. Once imported, the point coordinate values and attributes were converted, by the GIS, to a table format which could easily be viewed. Using GIS modeling equations, GLEAMS and REMM model input parameters were later added, as attributes, to the point table in columns appended to the table. This point table and its attributes were associated with the field areas via the point-in-polygon method.

In the SPANS GIS, transforming the coverage vectors (which made up arcs that outline the field and riparian areas) to a map involved a two-step process. The vectors were first converted to polygons. This procedure added topology to the coverage; that is, entities of the coverage (points, polygons) were spatially related to each other. Then the polygon coverage was transformed into a map. At this point the quad level of the study area was determined. The quad level determines the minimum size cell allowed in the quadtree structure. A quad level of 12 was selected which resulted in a resolution of 0.2 m, meaning the smallest cell size at the map scale represents an area 0.2 × 0.2 m. The quad level was selected based on the accuracy of the original survey of the area.

The SPANS GIS digitizing software, TYDAC, along with a Summagraphics digitizing tablet were used to digitize the soils coverage from a Soil Conservation Service soil survey photo (USDA, 1983). The photo was georeferenced using a 7.5-min USGS Quad map containing the test site. Coordinates of points identifiable on both the quad map and the soil survey photo, e.g. crossroads, were obtained from the quad map. The coordinates of these ground control points were then used to geographically locate the soils map.

After digitizing the soils coverage, points were added to each soil polygon for use in the point-in-polygon process. As with the test site coverage, unique identifying numbers were attached to each polygon point. Level numbers were also attached which identified the type of soil within each soil polygon.

The soil coverage vectors were exported from the digitizing software and imported into the same GIS project study area as the fields/riparian area coverage. As for the fields/riparian area coverage, the soil vectors were organized into polygons and converted to a GIS map.

The soils map was displayed in combination with the field and riparian areas vectors. It was noticed that the soils and field/riparian area coverages did not coincide with the soil survey photo/map. Adjustments were made to the soils coverage georeferencing coordinate values until, through visual inspection, the GIS coverages matched the survey map/photo. The discrepancies were attributed to inherent distortion in the soils photo and the large difference in photo/map scales, i.e. the photo scale was 1:20,000 and the field/riparian scale was 1:1,800.

The GLEAMS model gives the surface and subsurface hydrology outputs in terms of the entire upland agricultural area. The input into each individual riparian area is a portion of the total upland output. Determining the portion of the upland area whose output moved into a particular riparian area was done by digitizing an available contour map of the upland area and manually determining flow area boundaries (fig. 3). The flow boundaries outline subwatersheds whose outputs are the inputs of the riparian areas.

After building the partition map, the SPANS GIS command AREA was executed. This command gives a statistical report containing the square area of each polygon of a map and its percentage of the total area. These percentage values were later entered into the parameter tables for use in determining the amount of upland hydrology output entering each riparian area.

MODEL PARAMETER LOOKUP TABLES

Building the model input files required the assimilation of several parameter values. Ideally, large databases containing characteristics of various soil types, land management systems, and groundcover could be probed to obtain these values. However, due to the lack of site-specific data and the variance of these characteristics over relatively small areas, it was necessary to build small attribute tables containing only information pertinent to the land cover and soils in the test area.

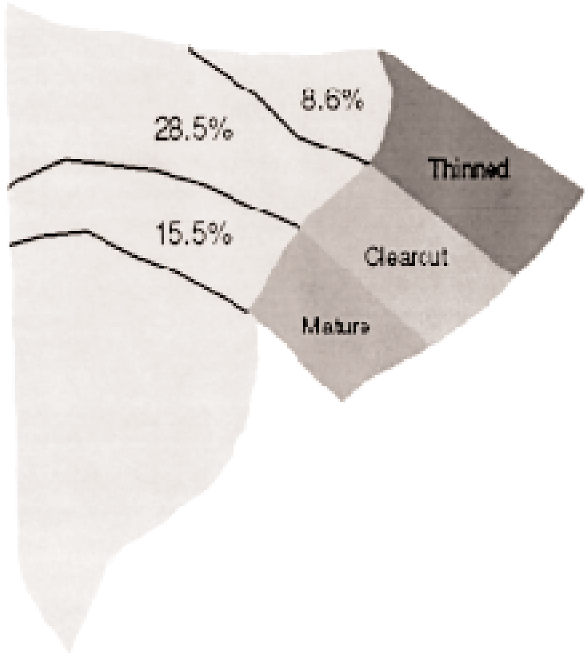

Figure 3–Upland area partitions for contributing percentages to the riparian areas based on topographic characteristics.

The GLEAMS and REMM models require hundreds of input values for model execution. Therefore, gathering valid data can be a formidable task. Because the test site is part of the Coastal Plain Experiment Station and has been the site of agricultural studies for several years, many of the required model input parameter values were readily available. Even so, input values for this study area ranged from very accurate to estimations. Care was taken to critically assess parameter values that, according to the models' literature, had a large impact on runoff and shallow subsurface water movement.

Many of the soil-related values were selected from Perkins et al. (1986). The GLEAMS manual and parameter editors also contain several tables from which parameter data was obtained (Knisel, 1993). These data included plant characteristics such as leaf area index and properties, such as Manning's "n", pertaining to soils and tillage practices.

The input parameter attribute tables were built within the SPANS desktop mapping software package, MAP. This software automatically formats the table headers for the attribute tables, and allows the tables to be easily inserted into the SPANS GIS environment.

An additional field (column) was added to each record (line) in each table. A unique identifying number was entered into this field. This identifying number tied the table to other attribute or map tables having the same number in a lookup field. After all parameter lookup tables were constructed, they were imported from the MAP environment into the GIS environment.

The GLEAMS and REMM models represent the soil profile differently. The REMM model divides the profile into three layers (fig. 1). The GLEAMS model allows the user to set the number of layers up to a maximum of five and only requires the description of those layers in the plant root-zone. Although some soil parameters are required for both models, some are not. For these reasons, two different sets of soil lookup tables, one set for each model, were constructed.

Five different soil series were present within the study area. Lookup tables were made for each model which contained soil parameter values for each of the five soil series. A column was added to each record in the table for a unique identifying number associated with the particular soil series. The number also provided a lookup value for appending the soil table data to parameter file tables.

GIS Modeling of the Test Site

A particular GIS command was used to extract the upland area records from the study site table containing records on both upland and riparian areas. The command formed a new table with only the upland area records. Likewise, commands were used to extract the riparian polygons from the original study site table. Using the GIS Model/Reclassification/Build Map/From Table command, the level and polygon identifying values of the new tables were used to build two new maps (one showing only the upland area and the other the riparian zones). The upland area table was exported from the GIS and imported into the MAP environment where parameter headings, not related to soil properties, were appended. The table was then re-imported into the GIS.

Before appending the soil data onto the tables, the dominant soil in each upland area and riparian zone had to be determined. This was accomplished using inherent GIS commands and modeling equations. A map was first created that included only the portion of the soils map that fell within the study site boundaries. A series of modeling equations and GIS routines were then used to identify the dominant soil types within each coverage polygon, and then select that soil type for the particular polygon (Tucker, 1998).

The parameter tables were completed by importing the soil and cropping parameters into a single file. In addition, the names of the files containing weather data for the GLEAMS model were appended. The parameter table was then exported and converted into a text file, via a created C subroutine, into the format of a GLEAMS input file.

The parameter table for the REMM model was completed much like the GLEAMS parameter table. However, building that parameter table required development of modeling equations to build one parameter table from the separate plant, litter, and three soil layer parameter lookup tables. The table was then exported from the GIS environment into the MAP environment where the upland area identifier, the percent of the upland area contributing to the particular riparian area, and the length of the upland area were added. Upon completion of the REMM input parameter table, it was exported, using a created C subroutine, into the text format required for REMM input constants.

The GLEAMS model requires a minimum of two parameter files, hydrology and erosion, for execution. An erosion input file was created using the GLEAMS erosion file parameter editor. No attempt was made to construct the file using the GIS table and modeling equations.

Once the GLEAMS hydrology, erosion, and weather files were completed, the model was executed. The model gave a hydrology output which was summed for each month of the simulation. GLEAMS allows the user to output specific values to a separate output file. The daily precipitation, runoff, and percolation amounts were output to a file for use as inputs into the REMM model. In this study there was only one upland area; therefore, the GLEAMS model was executed only once.

After running the GLEAMS model, the resulting output was input into the GLEAMS to REMM subroutine for proper formatting of the surface and subsurface outputs for input as the REMM field inputs file. This subroutine also provided algorithms for partitioning the percolation values into groundwater and lateral subsurface water movement (Tucker et al., 2000).

For each riparian zone, a text file containing the location and name of the REMM five input files was required. These were made for each zone with the weather and field input files being identical. Also, default values were used for all input parameters pertaining to the REMM nutrient module as this module was not addressed in this study.

Subsequent runs of the GLEAMS and/or REMM models were performed in the same manner. Input parameter values in the model input files were changed by editing the parameter files within the MAP environment. After completion, parameter values were exported, using created C subroutines, into the proper format for GLEAMS and REMM model input files.

Simulation results were evaluated using standard statistics on the monthly time frame (averages, paired-comparison t-test, correlation; Quattro, 1994). The primary consideration was to calculate the relative difference between simulated and measured response for an estimation of the accuracy of the model results. The paired-comparison t-test approach is designed to provide the simplest comparison statistics while assuming similar population characteristics between the simulated and measured results. Without extensive knowledge about the population dynamics, the alternatives of different statistical techniques do not provide extensive new knowledge to the comparisons. This type approach has been used in other applications under similar conditions (Thomas and Beasley, 1986).

The analysis of simulated versus measured results includes some discussion of acceptable/reasonable/good and unacceptable/unreasonable/poor performance of the model system. These terms are extremely subjective and have different interpretations by any particular model user and model developer. Those comparisons which were statistically different, but were within an order of magnitude, were termed acceptable. Those comparisons which were statistically different, and were not within an order of magnitude, were termed unacceptable. The primary concern in these determinations is the potential need for further development of the model for the conditions simulated.

Results

Subsurface shallow groundwater levels and surface runoff from the different riparian areas were the two model outputs used in the analysis. Simulated shallow groundwater levels were compared to measured data gathered from the test site from 1992 to 1994. During this period, shallow groundwater levels were monitored using several shallow wells within the zones and between the agricultural and riparian areas. The specific wells used in this analysis correspond to the central point within the riparian areas and represent the average conditions of the managed forest areas (Bosch et al., 1996). Shallow groundwater levels were relative to a 30.5-m elevation benchmark located at the test site. The REMM model outputs were consolidated on a monthly basis for total runoff and average shallow groundwater level.

SHALLOW GROUNDWATER LEVELS

Figures 4 to 6 illustrate the simulated and measured shallow groundwater levels for the clear-cut, thinned, and mature forest management condition within Zone 2 of the riparian area, respectively. The model system did the best job of representing the uptake and water table conditions under the thinned forest practice (fig. 5 and table 1). Under the clear-cut management situation, the model system may have overestimated the water uptake in the summer months from the undergrowth vegetation which typically regrows quickly after trees are removed. In the southeastern United States, it is not uncommon for a clear-cut area to be completely covered with vegetation within a short period after removing mature trees, with a relatively high water uptake rate (Lowrance et al., 1997). The model system underestimated water uptake from the mature forest management condition, especially during the months when evapotranspiration was greatest. Also, if the contributing area for surface and subsurface flow from the upland area is not representative of actual conditions (as is potentially the case with the mature forest treatment in fig. 6), simulated results will not be comparable to measured results. The shallow groundwater levels from the GLEAMS/REMM system were not as sensitive (or as variable) as the measured shallow groundwater levels. In general, the model system responded to the forest management conditions in the same range and relationship as the measured results (table 1).

The statistical analysis in table 1 also indicates that the thinned forest management conditions were better represented by the model, although the average monthly simulation results were all within one standard deviation of the measured water levels. With a low average difference in the water table simulation versus measurement of 0.08 m for the thinned forest management treatment to a high of 0.25 m for the mature forest, the model system was capable of representing the measured conditions. The paired-comparison t-test revealed either significant or highly significant differences for all three forest management conditions indicating that the model system can benefit from future improvements, or improved parameter identification may be necessary. The modeled vs. measured results had r^2 values of between 0.78 and 0.90 indicating that the trends were reasonably represented for all three forest management treatments.

SURFACE RUNOFF

Figures 7 and 8 illustrate the simulated and measured monthly total runoff from the combined upland and forest management treatments, respectively. In most cases, the model representation between the mature and clear-cut

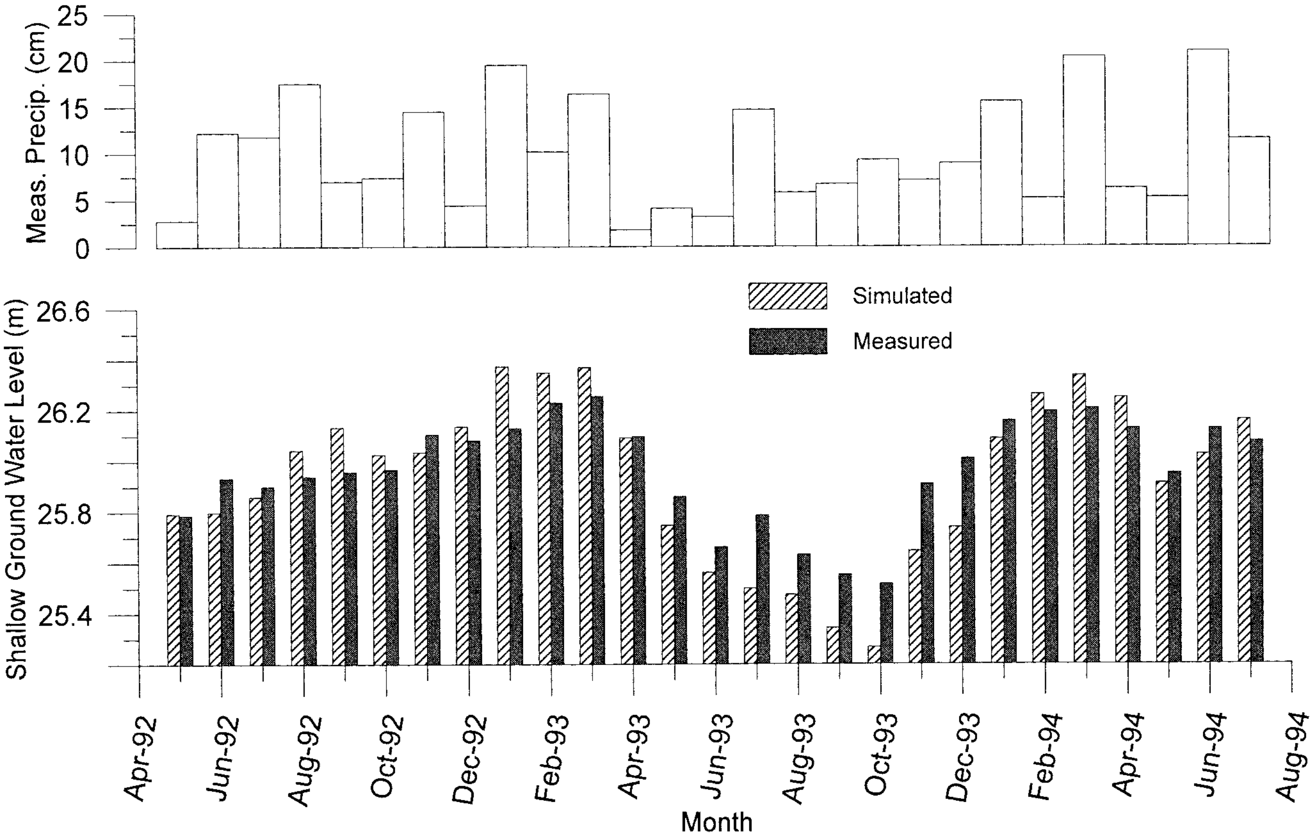

Figure 4–Simulated and measured shallow groundwater levels for conventional upland corn production contributing to a clear-cut forest site at the Gibbs Research Farm.

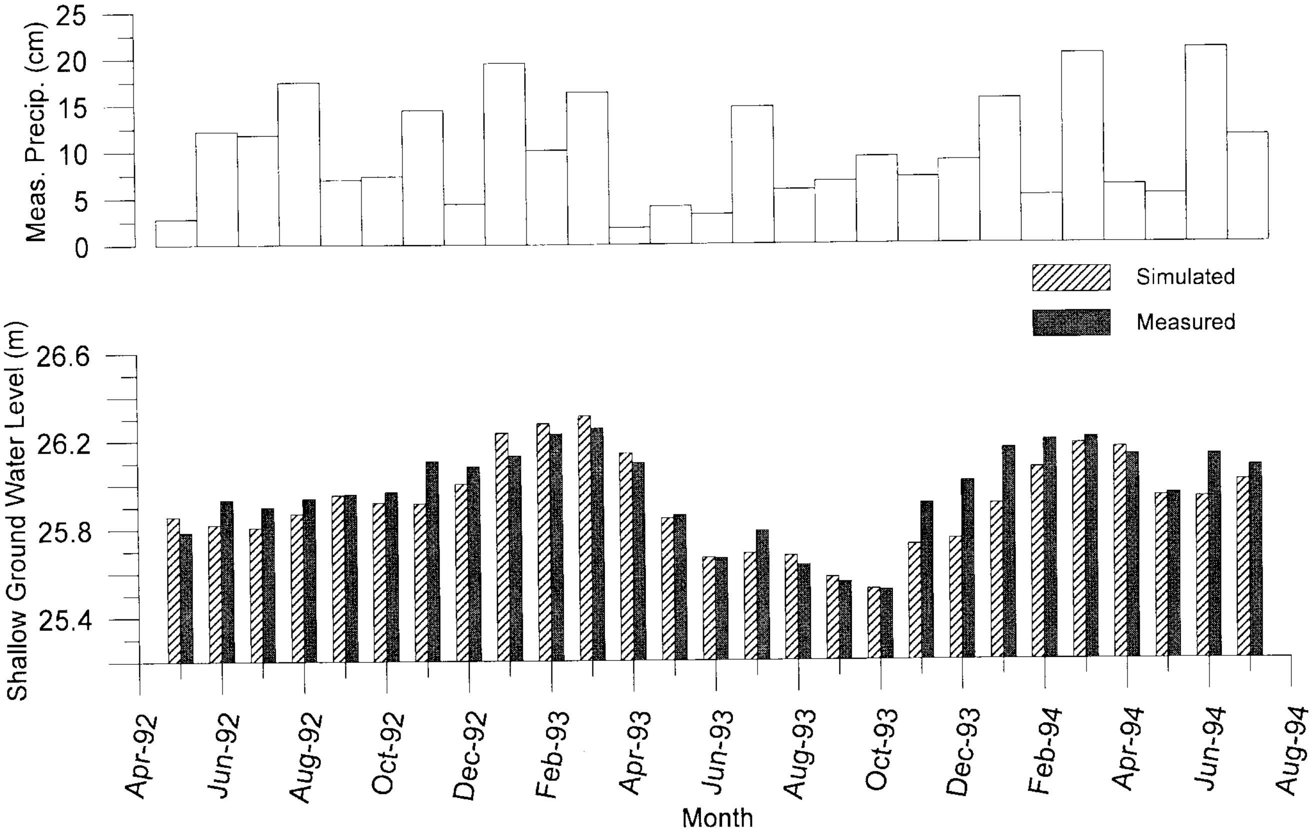

Figure 5–Simulated and measured shallow groundwater levels for conventional upland corn production contributing to the thinned forest.

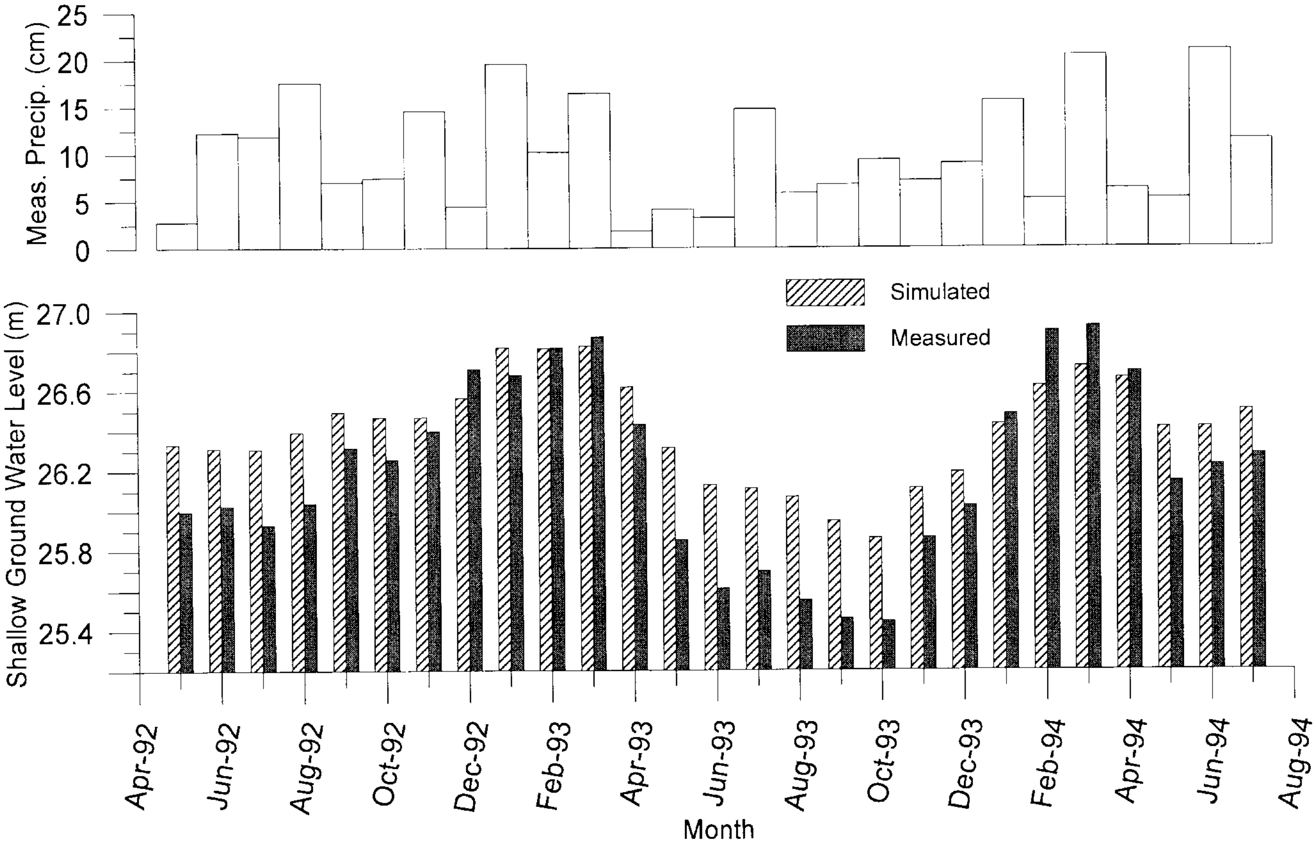

Figure 6–Simulated and measured shallow groundwater levels for conventional upland corn production contributing to the mature forest.

Table 1. Statistical analysis for monthly average shallow groundwater levels and monthly total runoff

	Average Shallow Groundwater Levels (m, over 27 months) for Forest Management Practices			Total Monthly Runoff (cm) from Zone 2 (over 27 total months) for Forest Management Practices		
Value/Test	Clear-cut	Thinned	Mature	Clear-cut	Thinned	Mature
Measured (SD*)	26.06 (0.28)	25.97 (0.21)	26.21 (0.45)	0.75 (1.05)	1.29 (1.37)	0.53 (0.80)
Simulated (SD)	25.94 (0.32)	25.91 (0.21)	26.40 (0.26)	0.15 (0.50)	0.10 (0.43)	0.09 (0.42)
Average difference between measured and simulated (Absolute value)	0.14	0.08	0.25	0.73	1.19	0.48
Paired-comparison t-test, two tailed (measured vs. simulated)†	**	*	**	**	**	**
Correlation between measured and simulated (r^2)	0.78	0.78	0.90	0.05	0.14	0.10

* Standard deviation.

† ** highly significant difference ($P < 0.01$), * significant difference ($0.01 < P < 0.05$).

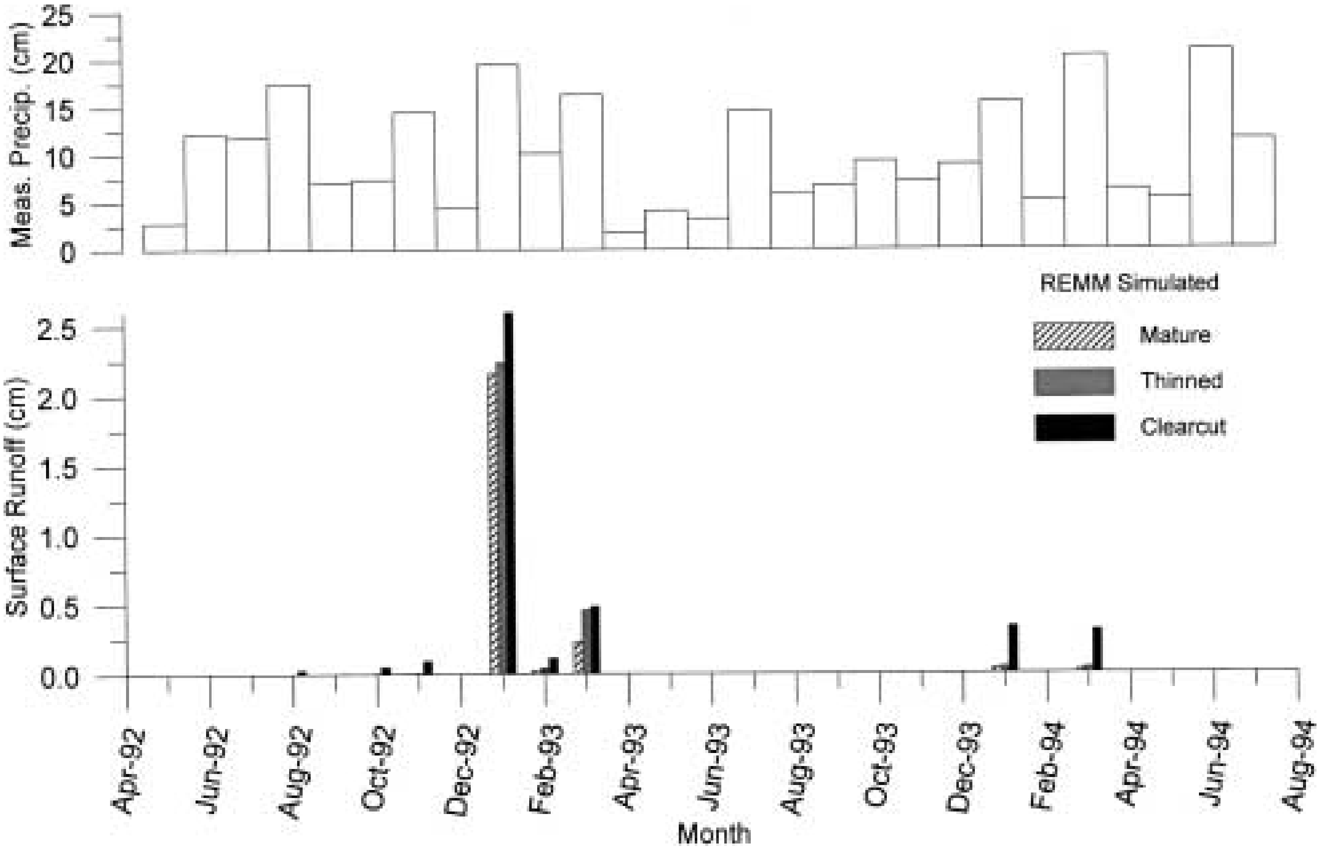

Figure 7–Simulated monthly runoff with the REMM/GLEAMS system for three different forest management treatments of mature, thinned, and clear-cut downslope from the upland corn production area at the Gibbs Farm Research Site.

management treatments were in the same direction. However, the measured runoff from the thinned forest management treatment was not represented well. table 1 indicates that the total monthly measured runoff from the thinned forest management treatment was exceptionally higher than either the clear-cut or the mature forest treatment. Previous studies have indicated that the ephemeral stream impacts shallow groundwater on the lower riparian landscape. This boundary effect combined with increased seepage due to the decreasing soil profile thickness above a restrictive subsurface horizon increases the runoff (Bosch et al., 1994; Sheridan et al., 1999). During the wet periods when runoff occurred in the forest areas and the stream was flowing, runoff from Zone 2 was essentially the same as runoff into the stream (Lowrance et al., 1997).

Figure 7 illustrates the model runoff outputs for the three riparian areas over the three year cropping period. As expected, the treatment area with the clear-cut Zone 2 produced the most runoff. The Zone 2 mature forest had the least amount of runoff. In all months except March 1993, the runoff levels for the thinned Zone 2 were very close to the amounts from the mature forest treatment. This result seems to indicate that riparian areas where trees are thinned should be nearly as effective as full growth mature forest in reducing surface runoff volumes. The disturbance to the soil associated with harvest activities can affect surface flow pathways, thus reducing runoff and

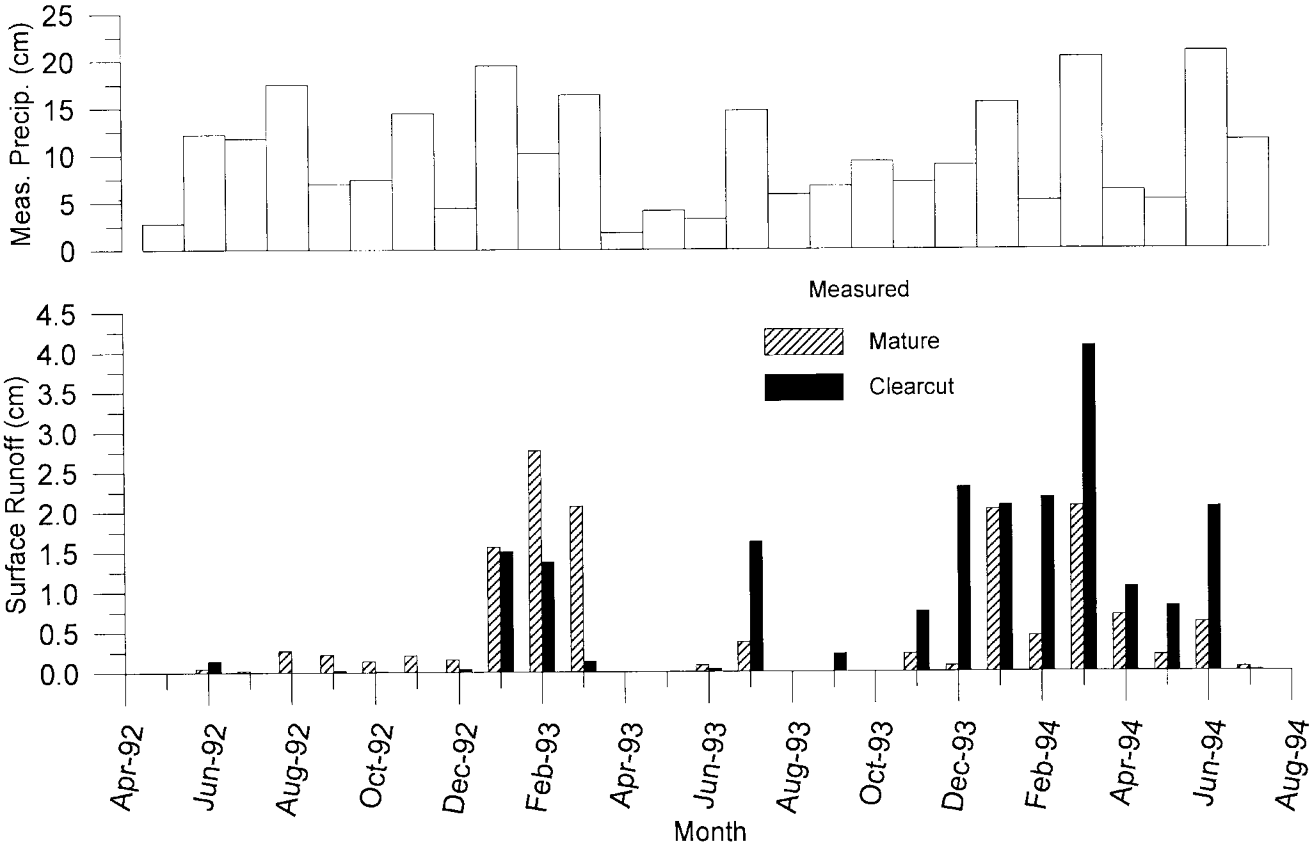

Figure 8–Measured monthly runoff for mature and clearcut forest treatments leaving Zone 2 at the Gibbs Farm Research Site.

encouraging ponding and infiltration. Table 1 indicates that the GLEAMS/REMM model system did the best job of representing the field conditions for the mature forest. However, all simulated vs. measured runoff results were highly significantly different based on the model system grossly underestimating total runoff. One potential problem with the model system may have been the inability to fully capture long-term seepage characteristics and return flow to the surface due to subsurface soil saturation and the stream flow boundary effect.

CONCLUSIONS

A GLEAMS/REMM model system was developed which allowed GIS-based management of data between input data sets and simulation results for potential improvement in scenario evaluations. Programs and subroutines were developed to allow delineation of field areas, identification and maintenance of data based on the field map, and incorporation of data to input data format.

The model system was capable of representing the shallow groundwater levels from forest management practices of clear-cut, thinned, and mature forests in field comparisons with data from the Gibbs Research Farm near Tifton, Georgia. Simulated monthly average shallow groundwater levels were within 0.14, 0.08, and 0.25 m of measured groundwater levels for the clear-cut, thinned, and mature forest treatments, respectively. Correlation results for the same treatments indicated at least an r^2 of 0.78, 0.78, and 0.90 for simulated versus measured shallow groundwater level results from the clear-cut, thinned, and mature forest treatments, respectively.

The model system did not respond as well in representing field conditions on total monthly runoff. Average monthly differences in total simulated runoff were 0.73, 1.19, and 0.48 cm lower (highly significantly) than measured results for the clear-cut, thinned, and mature forest management treatments from the Gibbs Farm Research Site near Tifton, Georgia, respectively, over the 27-month period of evaluation. No correlation was indicated between simulated and measured total runoff. However, the model system did indicate the runoff trends expected due to changes in forest management. As the number of trees and canopy increased, runoff decreased.

The need for additional model development from the REMM version used in this simulation appears to be desirable with respect to surface runoff processes. The authors also recommend further studies into the parameter development and data management process. Although the GIS-based approach is designed to provide a more seamless and integrated modeling system, unfortunately this approach is more cumbersome and requires greater computer skill. The utility of such an approach will not be extensively applied until many of the required routine operations are easy to use from existing data base sources.

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