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MODELING HYDROLOGY AND IN-STREAM TRANSPORT ON DRAINED FORESTED LANDS IN COASTAL CAROLINAS, U.S.A.

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ABSTRACT

This study summarizes the successional development and testing of forest hydrologic models based on DRAINMOD that predicts the hydrology of low-gradient poorly drained watersheds as affected by land management and climatic variation. The field scale (DRAINLOB) and watershed-scale in-stream routing (DRAINWAT) models were successfully tested with water table and outflow data from a 25 ha, 340 ha, 2950 ha forested watersheds and an 8140 ha mixed land use watershed in North Carolina (NC), USA. Results of linking DRAINWAT with a simple in-stream nitrogen transport model with a first order decay rate indicated its potential use as a tool for estimating N losses from the poorly drained coastal watersheds.

INTRODUCTION

Large areas of forested wetlands in the Southeastern coastal plain of the U.S. were developed or altered prior to 1980 by providing artificial drainage for agriculture and more intensive silviculture (Amatya et al 1997). In recent years there has been a great deal of concern about both the large quantities of fresh water outflows and quality of water drained from these lands, which are located adjacent to nutrient sensitive rivers and estuaries. In order to quantify the interactions and cumulative impacts of many processes and parameters affecting hydrology and water quality from these lands, researchers have developed models that are capable of simulating the hydrology, including the routing of flows and pollutant loads through a network of drainage canals and natural streams. When successfully developed and tested, such models can be used to identify combinations of practices that will enhance productivity and reduce environmental impacts (Heatwole et al 1987, Skaggs 1999, McCarthy & Skaggs 1992, Amatya et al 2003). However, most of the models have been developed for the upland watersheds with different hydrologic and in-stream hydraulic processes compared to low-gradient poorly drained lands of the lower coastal plains. The main objective of this paper is to summarize the successional development and testing of DRAINMOD (Skaggs 1978) based field and watershed-scale hydrologic models on four different low-gradient predominantly forested watersheds of various sizes and with varying management practices in coastal North Carolina (NC) in U.S.A.

MATERIALS AND METHODS

Site description

The **first study site** (D1) called "Carteret" is located in Carteret County, NC, USA (Fig.1.). This is one (control) of the three artificially drained experimental watersheds, each about 25 ha in size, planted to loblolly pine (*Pinus taeda L.*) in 1974.

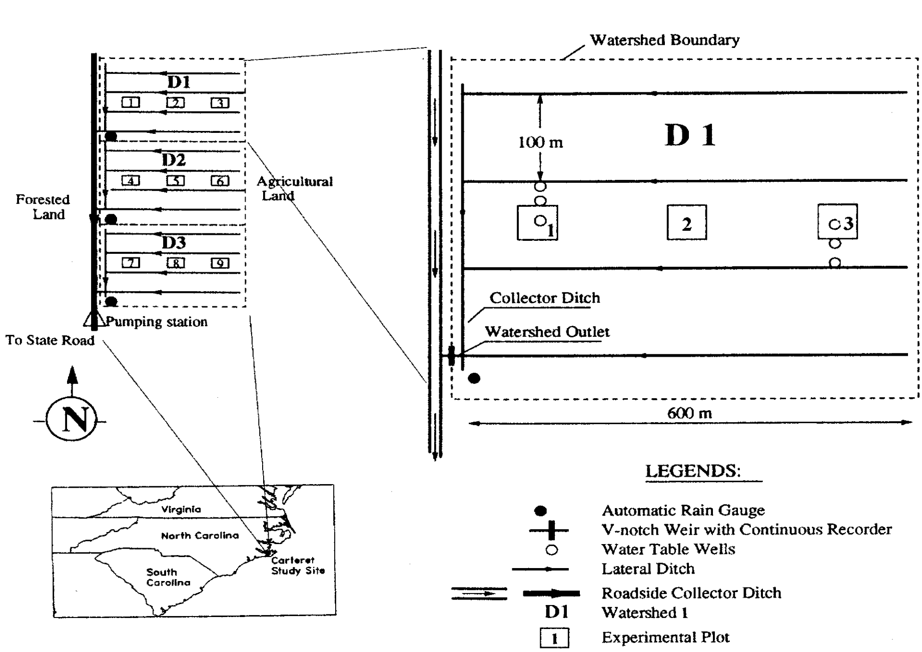

Fig.1. Location and layout of the Carteret watershed (D1)

The soil is a hydric series, Deloss fine sandy loam (fine-loamy mixed, Thermic Typic Umbraquult). Each watershed is drained by four 1.2 to 1.4 m deep parallel ditches spaced 100 m apart with outlets to a roadside collector ditch, which ultimately drains to an estuary about 3 km downstream (Tab.1). An automatic rain gauge and a weather station at the site provided weather data needed for the study. Flow was measured at the outlet of the collector ditch (Fig.1.) with a V-notch weir and a datalogger. Details of the site are given by Amatya et al (1996).

Table 1. Physical characteristics of four study sites in coastal NC, U.S.A

	Study Sites in Coastal Plain of North Carolina (NC)			
Description	**Carteret (D1)**	**Cozier (C)**	**Parker (S4)**	**Kendrciks (C7)**
Location	Carteret County NC, USA	Carteret + Craven County, NC, USA	Washington County, NC, USA	Washington County, NC, USA
Watershed area	24.7 ha	340 ha	2950 ha	8140 ha
Average elevation above m.s.l.	3.0 m	2.6 m	6.0 m	5.0 m
Mean annual precipitation	1337 mm	1337 mm	1292 mm	1292 mm
Mean annual temperature	17.6° C	17.6° C	16.7° C	16.7° C
Drainage type	Artificial	Artificial	Artificial+ Natural	Artificial+Natural
Lateral ditch spacings	100 m	100 - 200 m	100 - 200 m	Variable to No ditch
Lateral ditch depth	1.2 - 1.4 m	0.9 - 1.0 m	0.7 - 1.0 m	Variable to No ditch
Collector ditch/canal depth	Not available	Yes	1.8 - 3.0 m	Variable
Natural stream depth	Not available	Not available	2.5 - 3.0 m	1.0 - 3.0 m
Bed slope of canals/streams	Not available	0.0001	0.0001	0.0001
Manning's Roughness	Not available	0.03 - 0.05	0.035 - 0.05	0.035 - 0.10
Land use/Land cover type	Pine forest	Pine and Hardwood	Pine and Hardwood	Pine, hardwood, agricultural lands, and riparian forests
Soil types	Poorly drained fine sandy loam	5 types - Poorly drained, sandy loam to organic muck	5 types - Very poorly drained to poorly drained, organic muck	8 types - wide varieties including poorly drained
Depth to impermeable layer	3.0 m	1. 7 - 2.5 m	2.0 - 3.0 m	Variable
Hydraulic conductivity	3.9 m day^{-1}	0.2- 5.0 m day^{-1} (top) 0.12- 3.6 m day^{-1} (bot)	2.4-12.0 m day^{-1} (top) 0.01-2.4 m day^{-1} (bot)	Variable Variable
Saturated water content	0.44	0.38 - 0.73	0.37 - 0.76	Variable
Wilting point water content	0.21	0.23 - 0.31	0.13 - 0.45	Variable

The **second study site** (C) called "Cozier" is also in Carteret County, NC (Fig.2.). It is a 340 ha area in the watershed of Isaac Creek, which drains to Adam's Creek, a tributary of the Neuse River estuary. The study site is comprised of three blocks (A, B, and C) with three different vegetative and water management treatments as described by Amatya et al (1997). Each of the blocks is drained by lateral and collector ditches, which have flashboard risers with V-notch weirs (Tab.1). Soils in the southern part generally consist of mostly organic soils (Dare, Pungo & Ponzer) with some mineral soils (Argent and

Arapaho) in the northern part. An automatic rain gauge at the site and weather data from the Carteret site was used in the study. A riser with a V-notch weir and a datalogger at the main outlet (Fig.2.) provided the measurement of flows. Readers are referred to Amatya et al (1997) for more detailed description of the site.

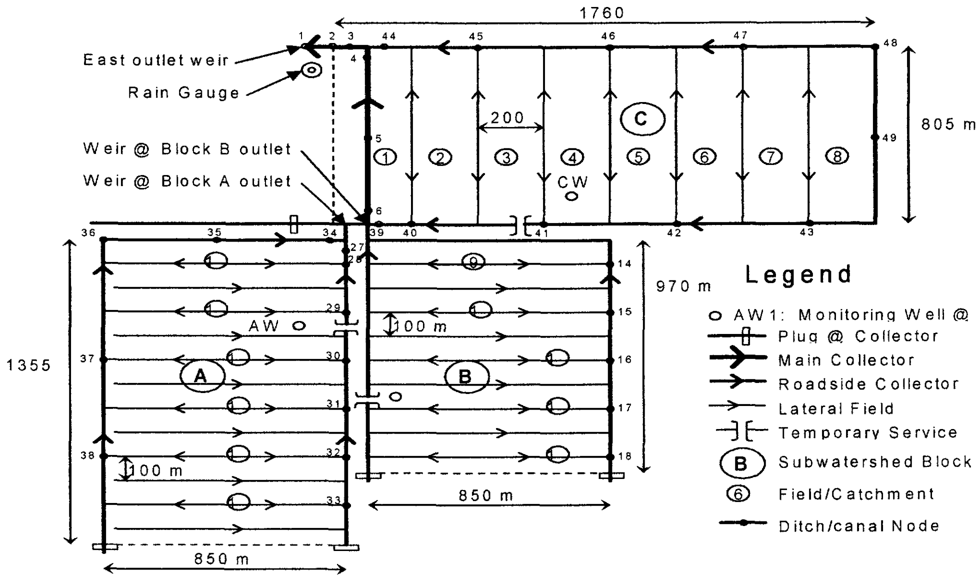

Fig.2. Layout of Cozier watershed (located adjacent to Carteret site in Fig.1. above)

The **third study site** (S4) called "Parker" is about 2950 ha in area and is part of a 10,000 ha watershed located near the town of Plymouth in Washington County, NC (Fig.3.). The site, which is very flat, is drained by collector ditches receiving drainage from lateral ditches, which are mostly 100 m apart. Seven mineral and organic soils are present in the watershed (Tab.1). The mineral soils in the northern part of the watershed are very poorly drained Portsmouth, Cape Fear and Wasda series, while organic soils, Belhaven and Pungo, are predominant in the southern half of the watershed. Surface vegetation in fields ranges from unharvested second growth mixed hardwood and pine forest to loblolly pine plantation (*Pinus taeda L.*) of various ages and stages. Three automatic rain gauges backed up by manual gauges in and around the site and an on-site weather station provided the weather data for the study. The outflow at the S4 outlet was measured using dual-span V-notch weir equipped with a datalogger.

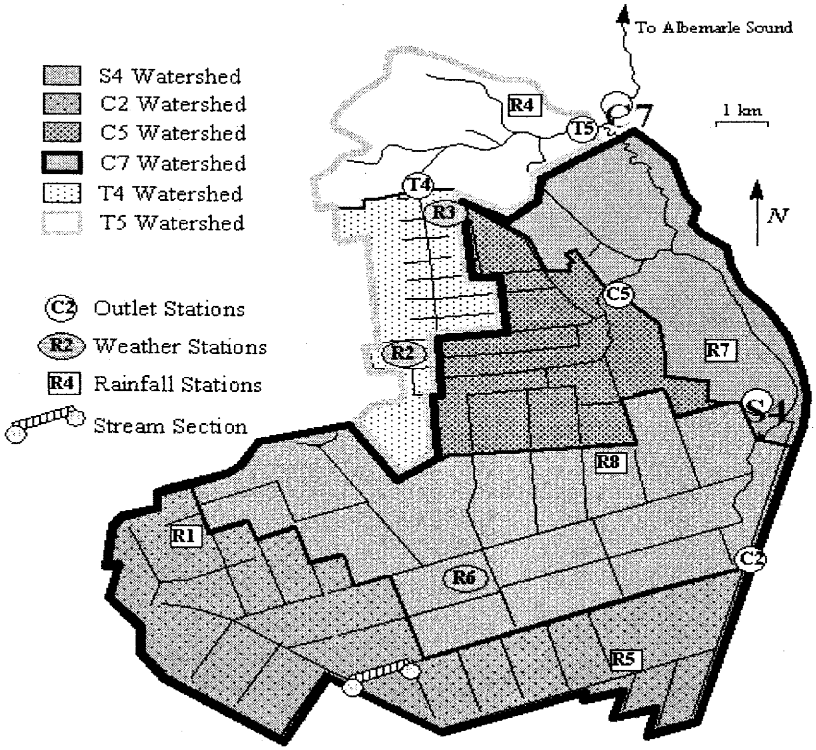

Fig.3. Layout of Parker (S4) and Kendricks (C7) watersheds along with monitoring stations

The **forth study site** (C7) called "Kendricks" drains about 8140 ha of land in the southern portion of the Kendricks Creek watershed also in Washington County, North Carolina (Fig. 3.). The drainage systems on the watershed include the major types used in the Coastal Plains. The primary system for both agricultural and forested lands is a network of field ditches and canals, which divide the watershed into a mosaic of regularly shaped fields and blocks of fields (Tab.1). The soils are very poorly drained and consist of both mineral (Portsmouth and Cape Fear series) and organic (Belhaven & Pungo series) soils. Land uses include cropland (36%), managed forested lands (52%), unmanaged forested wetlands and riparian areas (11%) and areas covered by buildings, lawns, roads, etc. (about 1%). These percentages of forest and cropland are typical for the region (Amatya et al 2003). The climate at the site is typical to the Atlantic Coastal Plain with hot and humid temperature during the summer often characterized by tropical storms and hurricanes. Data from five on-site automatic and manual rain gauges and two weather stations at and near the site were used for the study (Fig.3.). Flow at the triple-span box culvert outlet of the watershed was measured using a velocity meter. Detailed description of this and the Parker watershed site given above including their instrumentation and monitoring procedures can be found elsewhere (Amatya et al 2003).

Review of model development

DRAINMOD: A field scale agricultural water management model DRAINMOD (Skaggs 1978) uses a combination of methods, including the Hooghoudt equations for modeling subsurface drainage, Kirkham equation for subsurface drainage during ponded conditions, the Green-Ampt method for infiltration, and other approximate methods for quantifying other processes such as runoff, evapotranspiration and depression storage. DRAINMOD simulates the response of the soil water regime between ditches as affected by different combinations of surface and subsurface water management practices on agricultural and forested lands with shallow water table soils. Potential evapotranspiration (PET) for estimating ET is computed using the Thornthwaite method based on temperature, or daily or monthly PET values computed by any other method can be used. Canopy interception is neglected in the model. Rainfall in excess of infiltration is accumulated as surface storage specified for each field. The additional excess after satisfying the storage is allocated as surface runoff to the outlet, neglecting the overland flow routing process. Konyha and Skaggs (1992) suggested that the assumption of instantaneous runoff of surface water is reasonable only on small fields (about 5 hectares or less) but not on large fields. As the size of the field increases, the time needed to route the overland flow to the field outlet increases.

FLD&STRM: Konyha and Skaggs (1992) developed FLD&STRM model as a modified watershed-scale version of DRAINMOD by incorporating the overland flow routing as well as in-stream routing processes. In FLD&STRM, the rainfall excess computed at the midpoint of the field is first routed to the ditch via overland surface and then further routed to the subcatchment outlet using the ditch routing component of the model. The model first uses instantaneous unit hydrographs based on time of concentrations to simulate the overland flow routing in the field as well as in the ditch. Flow routing in the ditch is simulated as an in-stream component within the subcatchment to account for the delay in routing flow through the ditches to the outlet. Another significant addition to the model is that the one dimensional St. Venant equations for unsteady state flows are solved using numerical procedures for the main in-stream channel flow routing in the watershed, thus, taking care of changing ditch boundary conditions, backwater effects and tidal surges characteristics of watersheds in the low-gradient coastal plains. The channel-stream network is approximated as a finite number of stream elements and junctions at branching channels for which equations for conservation of mass and momentum are solved simultaneously to determine depth and flow rates. The model output of watershed outflow was found to be sensitive to time of concentration (T_c) in the fields, bottom slope of the main channel, and channel roughness (Konyha & Skaggs 1992).

Konyha & Skaggs (1992) reported that on relatively well-drained fields, much of the storm runoff is due to rapid subsurface drainage. During and immediately after a storm event, the water table profile is not elliptic, as assumed in Hooghoudt equation used in the FLD&STRM. Rather, it is more nearly flat, with high gradients near the ditch and higher subsurface drainage rates than predicted by Hooghoudt equation in which case Kirkham equation is used.

DRAINLOB: McCarthy et al (1992) modified DRAINMOD by replacing Hooghoudt equation of subsurface flow by the solutions of Boussinesq equations to obtain more accurate predictions of subsurface drainage, one of the major contributing components of forest water balance. This modified version of DRAINMOD, called DRAINLOB, was developed by adding interception and modifying ET and subsurface flow components of DRAINMOD to take into account these hydrologic processes.

Total evapotranspiration (ET) in DRAINLOB is calculated as the sum of wet canopy evaporation based on interception loss, soil evaporation and dry transpiration (McCarthy et al 1992). The surface runoff originates from canopy water balance as $I = \Sigma R_i - \Sigma H_i$, where, R_i = rainfall for time period i, cm. I = canopy interception loss, cm and H_i = throughfall precipitation for time period i, cm. Throughfall precipitation, which is available for infiltration in surface water balance, is then further defined as the sum total of $H = F + D$, where, F = free throughfall, cm, (proportional to percent open canopy) and D = canopy drip, cm.

Then the basic water balance for the surface runoff component of DRAINLOB is the same as for DRAINMOD described above, ignoring the overland and ditch flow routing within a subcatchment. However, because of large depressional storage on forest floors, surface runoff will, generally, be an insignificant portion of the total drainage outflows, which are dominated by subsurface drainage. Kirkham's equation is used for predicting subsurface drainage during ponded water conditions as it is in DRAINMOD. However, subsurface drainage flux, for the rest of the periods, is computed using average water table conditions in the entire soil profile, which are obtained by solving non-linear Boussinesq equations (McCarthy & Skaggs 1991). By doing so, the total drainage flux, including that from bank storage released during the transition from ponded water conditions to elliptic water table profile are addressed in DRAINLOB. Thus, this method, compared to DRAINMOD or FLD&STRM, is capable of predicting drainage flux as affected by bank storage. This is relevant to forested watersheds, which have much larger ditch spacings than in agricultural lands. But they have also large saturated conductivities.

The Penman-Monteith evapotranspiration method was incorporated into DRAINLOB to estimate forest dry transpiration and wet canopy evaporation based on hourly weather data, leaf area index and stomatal conductance function. In the model, when the canopy is completely wet, no transpiration is allowed. Transpiration is assumed to occur when the canopy is dry. Based on the storage in the canopy, both transpiration and evaporation from the wet surfaces can occur during a given period. For the period when there is no more wet canopy evaporation, the model calculates transpirational losses same way as in DRAINMOD. Soil or ground evaporation is calculated as a function of potential ET decreasing exponentially with leaf area index parameter. McCarthy et al (1992) tested this modified model with 22 months of data from the Carteret study site, the 25-ha drained pine forest. Other details of the modeling procedures and model parameterization are given by Amatya & Skaggs (2001) and some are shown in Tab.1.

DRAINWAT: DRAINmod for WATersheds was developed linking DRAINLOB with the overland flow, ditch and in-stream flow routing components of the FLD&STRM model. The distributed model operates as a sequenced set of simulations so that simulated outflow from each "field" (subwatershed) delineated with relatively uniform soil and stand conditions is first combined into the collector ditch of the subwatershed. The simulated combined outflow from one or more subwatersheds is then routed through the channel system to the watershed outlet. Use of the instantaneous unit hydrograph, based on time of concentration takes into account the time that is required for surface runoff to travel across the surface to the ditch and then further routed through the ditch network into the outlet of each subwatershed. These outflows are then used as lateral inflows for the in-stream routing component of the model. DRAINWAT, like FLD&STRM, uses numerical solution to the 1-D St. Venant equations to compute depth and flows at selected nodes along the stream or collector ditches. The model is also capable of taking the unsteady state flow conditions such as backwater effects, tidal surges, reservoir storages, etc. (Konyha & Skaggs 1992) into account while simulating the hydrology of poorly drained lands with mixed land use and their in-stream transport hydraulics.

The watershed-scale model was first tested with 5-years (1988-92) of data from the Cozier study site. The whole watershed was represented by 19 fields, 49 nodes including the location of lateral inflows, four branches (confluence of two canals) and three weirs for routing the flows along the ditch/canal system (Fig.2.). The numbers and areas of fields and their characteristics, hydraulic parameters of ditches and canals are summarized in Tab.1 and described in detail elsewhere (Amatya et al 1997). The model was also tested with five years (1996-00) of data from the 2950 ha Parker watershed. The watershed was delineated into 27 fields with varying areas (42 ha to 205 ha; 109 ha average) having common drainage, soils and vegetation management practices and 50 nodes in the channel-stream network. These included 27 field outlets serving as nodes for lateral inflows, seven in-stream weir structures and 16 for the branch nodes. Finally, the model was applied on the 8140 ha Kendricks watershed, to test its ability to predict the outflows. It was delineated into 50 fields with sizes varying from 36 ha to 243 ha (163 ha average). The delineation of main drainage canal network resulted in 183 nodes, 29 branches, and four in-stream weirs for model simulation. The main input parameters used in model simulations for all these three sites are presented below. Measured rainfall was the driving variable in the model at all sites. Because of lack of pertinent vegetation parameters for various type and stand ages of forests at Parker and Kendricks watersheds, only the Penman-Monteith REF-ET model was applied (Amatya et al 2003). Model inputs of soil hydraulic properties for various types of soils on both Parker and Kendricks Creek watersheds were obtained from published data. Model testing results are presented and discussed below.

Model Performance Evaluation: The performance of both the field-scale model (DRAINLOB) and the watershed-scale model (DRAINWAT) was evaluated by using graphical plots and statistical goodness-of-fit criteria. These criteria were Mean, Standard Deviation (SD), Average Absolute Daily Difference (AADD), Coefficient of Determination (R^2), and Nash-Sutcliffe Coefficient (E) between the predicted and measured values of water table depths and outflows for the daily and annual values as described by Amatya et al (1997, 2004).

RESULTS AND DISCUSSION

Carteret Site (D1)

DRAINLOB predicted and measured daily water table elevations (WTE) for the Carteret study site for the 10-year period (1988-97) are plotted in Fig.4. The model simulated water table elevations with an average absolute daily deviation of 0.15 m for the 10-year period. This was deemed to be acceptable, given the complexities in defining ground surface elevation on these bedded plantations. The model consistently overpredicted average water table elevations during peak events when water table elevation was about 2.25 m and higher. This indicates a possible discrepancy in drainable porosity around that depth. Interestingly, predicted draw down in the range of 1-1.5 m elevation was slower than the measured data in the May-June period of all years except 1989. As a result of this, a somewhat large overestimation of water table elevations occurred in the spring and early summer of 1995. The error is not caused by errors in hydraulic conductivity because no drainage occurs for that water table elevation. Apparently the discrepancy in this period is due to errors in either drainable porosity or predicted ET. Other goodness-of-fit statistics such as E (Nash-Sutcliffe coefficient) = 0.78 and $R^2 = 0.93$ further support the conclusion that the model can be used to reliably predict daily water table depths on poorly drained forested watersheds.

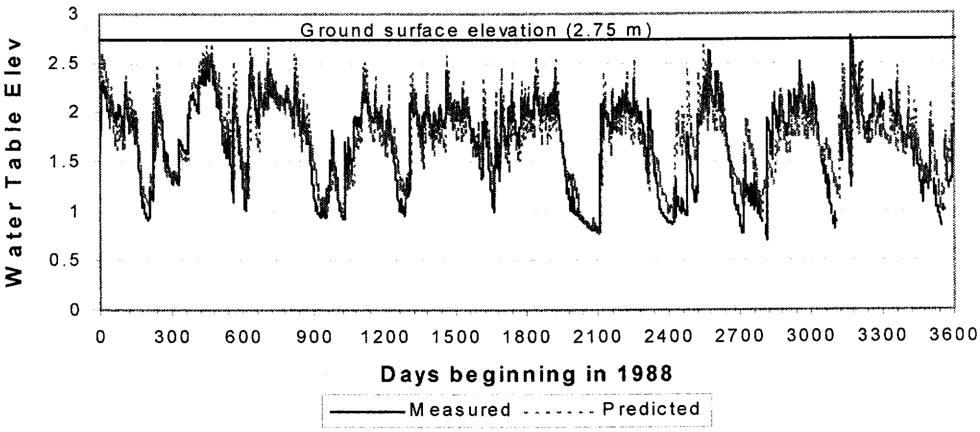

Fig.4. Measured and predicted daily water table elevations on watershed D1 for 1988-97

Table 2. Statistics for model performance for predicting outflow on four study watersheds

	Study Watersheds			
Description	Carteret (D1)	Cozier (C)	Parker (S4)	Kendrciks (C7)
Period of comparison	1988 - 1997	1988 - 1993	1996 - 2000	1998 - 2000
Measured Mean Daily Flow, mm	1.36	1.62	0.86	1.35
Predicted Mean Daily Flow, mm	1.36	1.48	0.83	1.54
Measured Std. Dev., mm	3.08	2.68	1.59	2.23
Predicted Std.Dev., mm	3	2.75	1.56	2.84
R^2	0.73	0.66	0.81	0.6
Nash-Sutcliffe Coefficient, E	0.72	0.62	0.8	0.34
AADD, mm	0.61	0.79	0.36	0.84

A plot of measured and predicted daily outflows for the first 7-year period (1988-94) is shown in Fig.5. for the Carteret site. The model predictions were in good agreement with the measured data as shown by the means and standard deviations (Tab.2). Average absolute error of prediction of daily drainage rates for the 10-year period with varying seasonal and annual weather conditions were within 0.61 mm d^{-1}. The ranges of R^2 and E values were 0.65 to 0.91 (average = 0.73) and 0.54 to 0.90 (average = 0.71), respectively.

The model over-predicted most of the summer events. On an annual basis the errors on drainage outflow varied from −18% (overprediction) to 23.1% (underprediction) with an average of 0.4%. Some of the larger differences between predicted and measured flow rates were attributed to both modeling and measurement errors. Use of the calibrated stomatal conductance function, developed using only weather data (from a distant weather station) in the Penman-Monteith ET submodel could have been a source of error in modeling ET, especially during the summer. The measurement errors were attributed not only to some extrapolated data but also to uncertainties in hydraulic conductivity and estimates of flow rates during large events causing weir submergence.

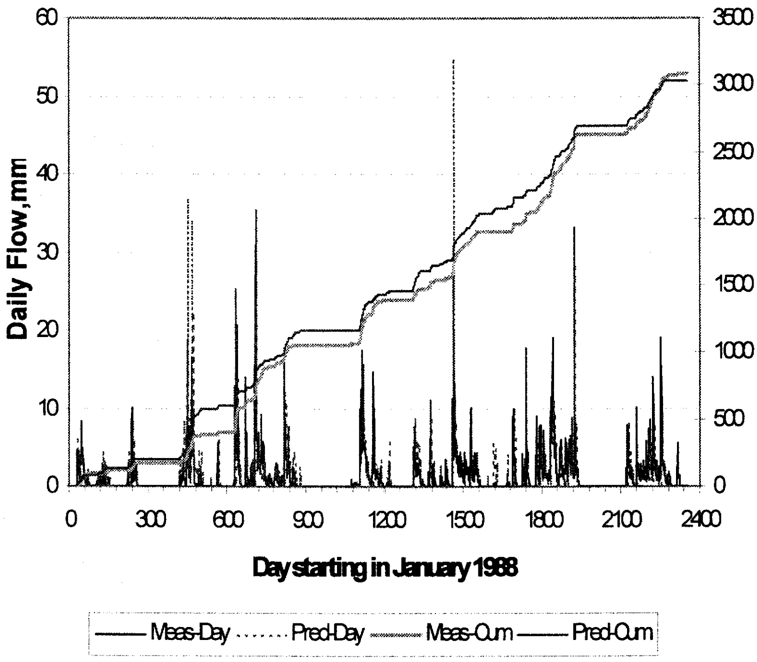

Fig.5. Measured and predicted daily and cumulative outflows for thewatershed D1 for the period of February 1988 to June 1994. Data after this only intermittent are not shown.

McCarthy & Skaggs (1992) applied DRAINLOB to simulate the effects of water and silvicultural (thinning and harvesting) management practices on this drained pine forest. The model was also successfully tested for predicting hydrology of these forests for controlled drainage conditions with raised weirs (Amatya et al 1994) and with an orifice and a flat weir at the watershed outlet (Amatya & Skaggs 1997) for various water management regimes.

Cozier Site (C)

The watershed-scale model DRAINWAT was first tested with measured data from the Cozier (C) watershed (Amatya et al 1997). Predicted and measured daily and cumulative outflows for the years 1988 and 1991 are plotted in Fig.6. Data showed that the model was able to capture all drainage events. Computed statistics are presented in Tab.2. The predicted mean daily outflow rate was about 10% lower than the measured data for the five-year period, consistent with the lower value of E compared to R^2. The average absolute daily deviation (AADD) in observed and predicted daily outflows for a five-year period was 0.79 mm/day. Based on R^2 and E statistics the model predictions of daily outflows were deemed to be acceptable. It was concluded that part of the error in prediction of outflows were due to errors in predictions of the field hydrology such as surface storage and seepage. A major source of model error was attributed to errors in computing ET, which is dependent on Leaf Area Index (LAI), stomatal conductance and weather variables. Results also suggested that in the absence of reliable data on these parameters, use of temperature based Thornthwaite PET or Penman-Monteith REF-ET for a grass reference might produce acceptable predictions.

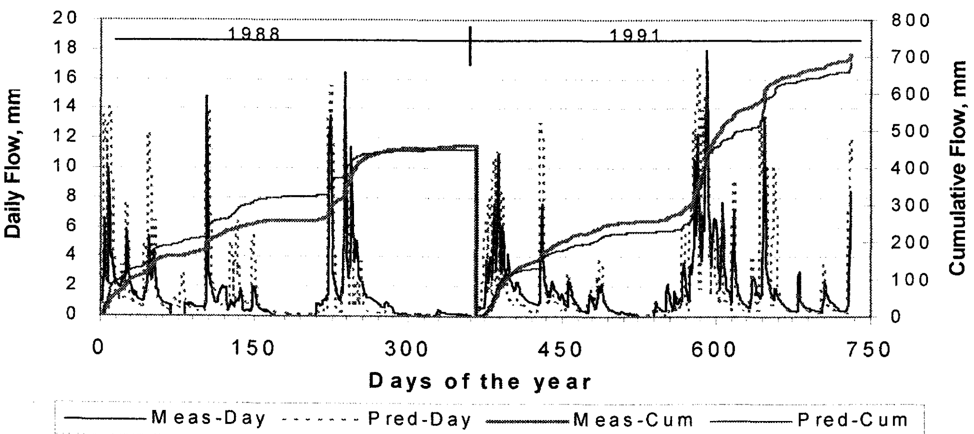

Fig.6. Measured and predicted daily and cumulative outflows for the watershed D1 for the period of February 1988 to June 1994

Parker site (S4)

Measured and DRAINWAT-predicted daily and cumulative drainage outflows for the Parker watershed (S4) are presented in Fig.7. for each of the five years (1996-2000). Model-predicted outflow from storm events was in close agreement with measured data, except for some days in the spring of 1997 and late winter of 1998. The model also did a good job in predicting the time distribution of outflows. Total cumulative outflow at the end of the five-year period was underpredicted by 90 mm, which was only 6.5% of the total measured outflow of 1404 mm. Part of this underprediction occured in the spring of 1997 when the model failed to predict an event. When considered on a year-by-year basis, the AADD parameter varied from 0.14 mm in 1997 to 0.41 mm in 1999 (average = 0.36) (Tab.2). The Nash-Sutcliffe coefficient ranged from 0.71 to 0.84, with 0.75 (average = 0.80), which is considered satisfactory. Errors in predictions were attributed to measurements of peak flow rates during large hurricane events causing weir submergence and spatial variability in rainfall.

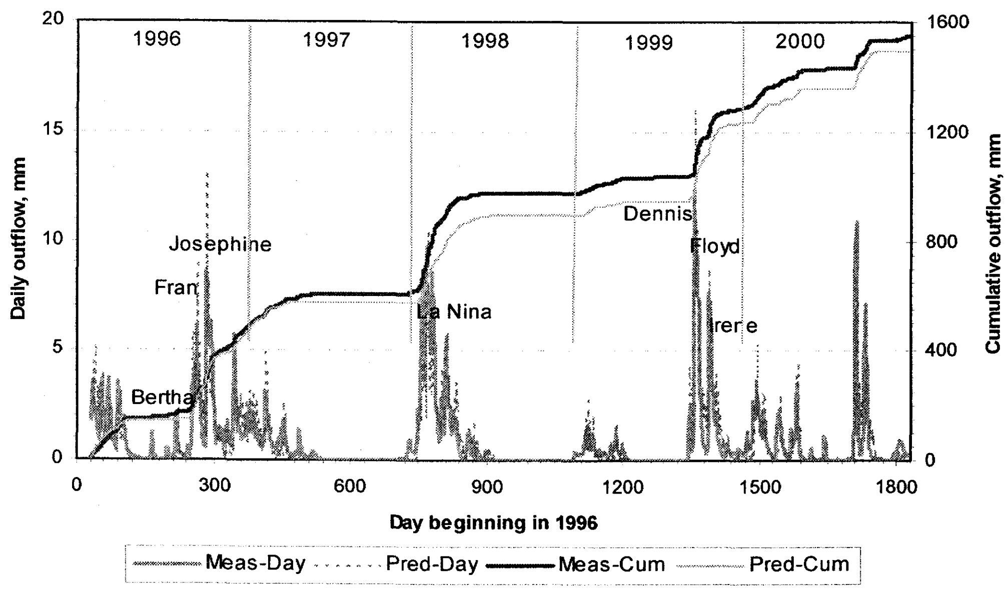

Fig.7. Measured and predicted daily and cumulative outflows for the Parker watershed S4 for the period of February 1996 to December 2000

In general, the results indicate that the published soils data and Penman-Monteith REF-ET without considering dry and wet canopy ET are adequate for this scale of watershed hydrologic modeling to predict daily outflows. However, results of testing the internal consistency of the watershed-scale model showed that intensive calibration and validation with multi-response data like water table depths (soil moisture) in the fields are needed to accurately quantify the hydrology of individual fields and in-stream hydraulics (Amatya et al 1999).

Using 8-years (1990-97) of weather data, the tested model was used to simulate the average distribution of flow velocities at various in-stream locations along the channel-stream network (Amatya et al 2003). The simulated average daily velocity was 0.03 m sec^{-1} and was as high as 0.45 m sec^{-1} at the downstream location during large events. Recently DRAINWAT was applied to estimate travel time of nitrogen (*N*) leaving the field-edge and moving to the watershed outlet along a specified pathway in the channel-stream network (Amatya et al 2004). Using this travel time in a lumped parameter model with a first order decay rate for *N* transport and DRAINWAT predicted outflows with estimates of *N* loading from each individual field, the predicted annual *N* watershed loadings for the same five-year period (1996-2000) were in good agreement with measured data.

Kendricks Creek site (C7)

Plots in Fig. 8 indicate that the DRAINWAT model was able to capture almost all drainage events on the Kendricks watershed (C7). However, it over-predicted measured outflows in most of the months of the three-year (1998-2000) period. Accordingly, the predicted mean daily flow was about 15% higher than measured for the 35-month period (Tab.2). The much lower E value (0.36) compared to R^2 (0.64) indicates prediction bias.

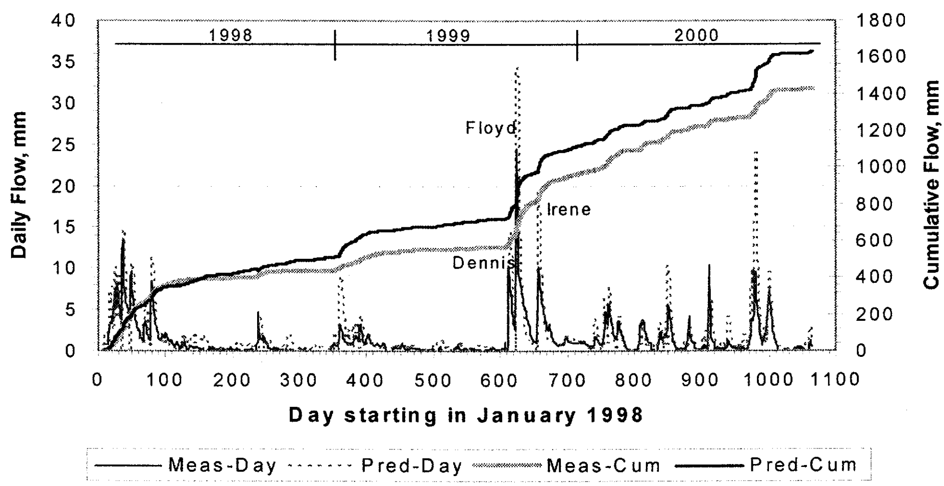

Fig.8. Measured and predicted daily and cumulative outflows for the Kendricks watershed C7 for the period of January 1998 to November 2000

Most of the over-predictions occurred in early 1999 and also during two large events in 1999 (Hurricane Floyd) and 2000. Others were due to over-prediction of small flow rates during the summer-fall periods possibly due to errors in subsurface drainage rates and/or ET. The watershed S4 (2950 ha) is also included in this watershed. Given the fact that the model predictions for the watershed (S4) were reasonable, except for large peak rates when the measured data itself may have been in error (Amatya et al 2002), over-predictions indicated in Fig.8. were apparently due to errors in predicted outflows from the remaining agricultural, forested and riparian lands, which constituted nearly 64% of the C7 watershed. Limited field calibration with rainfall (spatial variability), in-stream outflows, channel-stream dimensions and soil hydraulic properties likely contributed to the errors on this large watershed.

SUMMARY AND CONCLUSIONS

This paper summarized the successional development and testing of DRAINMOD (a widely used agricultural water management model) based field and a watershed-scale forest hydrologic model with an in-stream routing component on watersheds with various sizes and management practices. The goodness-of-fit statistics for model performance showed that both the field and watershed-scale models were able to predict the daily water table elevations and drainage outflows for varying soil type, land use and climatic conditions to an acceptable degree on the poorly drained coastal watersheds. The study also indicated that published data on soil hydraulic properties and Penman-Monteith based PET are adequate to model the daily outflows of these forested watersheds. However, with minimal field data, the performance for the largest watershed was poor compared to results for the other watersheds. This indicates that field calibration with multi-response variables may be necessary for more accurate predictions of spatial and temporal distribution of flows and velocities on larger watersheds. In another study DRAINWAT was successfully linked with a simple water quality model for estimating N transport. The model is currently being applied to predict lateral flows from fields, in-stream flow rates and velocities for estimating N loads and transport on a 65-ha agricultural watershed in northern coastal plain of Italy (Borin et al 2004). Research version of the DRAINWAT model in DOS format is now being upgraded with windows-based interfaces for its more user-friendly application. Three other DRAINMOD-based watershed-scale hydrologic and water quality models of various levels of complexities have also been recently developed and tested on poorly drained watersheds (Fernandez et al, 2002; 2005a; 2005b).

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