The Society for engineering in agricultural, food, and biological systems

Paper Number: 032167
An ASAE Meeting Presentation

Application of a DRAINMOD-based Watershed Model to a Lower Coastal Plain Watershed

Glenn P. Fernandez, Research Associate

Dept of Biological and Agricultural Engineering, NCSU, Raleigh, N.C.

George M. Chescheir, Research Assistant Professor

Dept of Biological and Agricultural Engineering, NCSU, Raleigh, N.C.

R. Wayne Skaggs, W. N. R. and Distinguished University Professor

Dept of Biological and Agricultural Engineering, NCSU, Raleigh, N.C.

Devendra M. Amatya, Research Hydrologist

USDA Forest Service, Charleston, S.C.

Written for presentation at the
2003 ASAE Annual International Meeting
Sponsored by ASAE
Riviera Hotel and Convention Center
Las Vegas, Nevada, USA
27- 30 July 2003

Abstract. . This is a case study for applying DRAINMOD-GIS, a DRAINMOD based lumped parameter watershed model to Chicod Creek, a 11300 ha coastal plain watershed in North Carolina which is not intensively instrumented or documented. The study utilized the current database of land-use, topography, stream network, soil, and weather data available to the State and Federal agencies. Methods for collecting, evaluating, and formatting watershed data for model input are described. The study demonstrated that the lumped parameter model may be used to characterize the hydrology and water quality of Chicod Creek. Hydrology predictions were within 1% of the measured data. Predicted mean daily flow weighted concentration compared well with the measured data. Mean annual delivery ratios of each field ranged from 59% to 99% with a watershed mean of 76%. Application of the model to evaluate the effects of changing land are presented.

Keywords. DRAINMOD, Drainage, Watershed Model, Water Quality

Application of a DRAINMOD-based Watershed Model to a Lower Coastal Plain Watershed

Abstract. *This is a case study for applying DRAINMOD-GIS, a DRAINMOD based lumped parameter watershed model to Chicod Creek, a 11300 ha coastal plain watershed in North Carolina which is not intensively instrumented or documented. The study utilized the current database of land-use, topography, stream network, soil, and weather data available to the State and Federal agencies. Methods for collecting, evaluating, and formatting watershed data for model input are described.*

The study demonstrated that the lumped parameter model may be used to characterize the hydrology and water quality of Chicod Creek. Hydrology predictions were within 1% of the measured data. Predicted mean daily flow weighted concentration compared well with the measured data. Mean annual delivery ratios of each field ranged from 59% to 99% with a watershed mean of 76%. Application of the model to evaluate the effects of changing land are presented.

Introduction

The impacts of excessive nitrogen (N) loading to streams are often manifested in the receiving waters (lakes, major rivers, or estuaries) at or below the outlet of the watershed. The non-point sources of N are usually well distributed among many fields or blocks within the watershed. Likewise, management practices that can be implemented to reduce N loading are distributed on a field by field basis throughout the watershed. In order to quantify the impacts of best management practices (e.g. land use changes and alternative management practices) on the N loading at the watershed outlet, simulation models are needed that can both predict the N loading at the field edge and the fate of N as it moves through the stream network to the watershed outlet. Various upland distributed parameter models exist for predicting the N loading at the outlet of watersheds. While these models are useful for upland conditions, the curve number method used to quantify runoff volume in these models is not applicable for the high water table soils of the lower coastal plain, as well as, other poorly drained watersheds. Accurately quantifying the drainage volume (both surface and subsurface) is essential to predicting N loading from a watershed. Since water table depth greatly affects outflow from high water table soils, a watershed model that considers drainage processes is necessary for predicting N loading from lower coastal plain watersheds.

DRAINMOD-based hydrology and water quality models have been developed to predict N loading at the outlets of coastal plain watersheds (Fernandez et al., 1997,2001,2002; Amatya et al., 2003). Since these models simulate water table depth and runoff volume from individual fields distributed throughout a watershed, they can account for management practices and land use changes that occur on the field scale and predict the cumulative impact of these changes on N loading at the watershed outlet. The DRAINMOD-based models have accurately predicted drainage volume and N load at the outlet of a well instrumented and documented watershed near Plymouth, NC (Fernandez et al., 2000, 2001, 2002; Amatya et al., 2003). This paper presents a case study of the application of this approach to predict nitrate loading from a coastal plain watershed which is not intensively instrumented or documented. The study utilized the current database of land-use, topography, stream network, soil, and weather data readily available to the consultants, and state and federal agencies who would eventually use the models. The application of the model to evaluate effects of changing land use is presented.

Watershed Scale Model

DRAINMOD-GIS (Fernandez et al., 2000) is a linkage of the field hydrology model DRAINMOD (Skaggs 1978, 1982) and a generalized spatially distributed canal routing model using a response function (Moussa et al., 1997; Olivera and Maidment, 1999). Field hydrology is simulated with DRAINMOD and the drainage network routing is modeled with an impulse response function using a first passage time distribution to characterize the time of travel in the flow path. The model uses a generalized approach to flow routing which considers spatially distributed inputs and parameters where drainage from contributing areas (non-overlapping) are considered separately instead of spatially averaged. DRAINMOD-GIS is a two parameter routing response function model (derived from first passage time distribution) and requires parameters which are related to flow time (advective velocity) and shear effects (dispersion) along the flow path.

In this model, DRAINMOD is used to simulate the water losses from contributing areas (either under controlled or conventional drainage). The water losses are then routed to the field outlets using an instantaneous unit hydrograph and eventually routed to the watershed outlet using the response function. The model requires stream velocities along the flow path from contributing area to the watershed outlet as inputs. These velocities could be determined from simulations using mechanistic models (Fernandez et al., 1997, 2001) or could be determined from flow records. For water quality, an exponential decay model is used to characterize the attenuation of a water quality parameter as it travels along the flow path. Although the model can use a field water quality model, such as DRAINMOD-N (Breve et al., 1997), to characterize drainage water quality at the field edge, concentrations based on values obtained from the literature were used in this paper.

Methodology

Site Description. The Chicod Creek watershed located near Greenville, NC was selected for the study. The watershed is 11300 ha in area and drains a combination of agricultural (55%), managed forest and natural forest lands (45%) (Figure 1). A drainage improvement project was implemented in 1972 (USDA SCS, 1971), which involved channelization and maintenance on the major streams and canal. Flow rates have been recorded at the outlet of the watershed from a gauging station operated by the United States Geological Survey (USGS) in cooperation with the North Carolina Department of Environment and Natural Resources (NCDENR) since 1992. Daily nutrient monitoring was conducted for a full year from February 1993 to February 1994 and again from February 1997 to February 1998 by (NCDENR).

The model requires input data for soil properties, land use and management practices, stream network configuration, and weather data. Many of these data are available in Geographic Information System (GIS) formats, which are becoming the standard input for spatially distributed parameter models. However, these data need to be verified in the field since some errors may exist. The overall procedure for this study was a) to collect the existing GIS database for soils, land use, topography and stream networ, b) make trips to the field to verify the data, c) to correct data as needed, d) prepare the data for model input, e) to make short term simulations and calibrate the model based on measured available data, and f) make long-term simulations of the watershed. Outputs of the model include outflow and loads at the edges of individual fields and at the watershed outlet. Delivery ratios could then be calculated for each field in the watershed.

Initial Data Collection. Our initial data collection utilized the current GIS database of land-use, topography, stream network, and soil data readily available to State and Federal agencies. The land use and land cover data (LULC) were collected by USGS and compiled into 1:250,000 quadrangle tiles. Topography data were 1:24,000 digital elevation models (DEM) compiled and made available through USGS. Stream network or hydrography data were in the form of 1:24,000 digital line graphs compiled and made available through USGS. Soils data were obtained from the Soil Survey Geographic (SSURGO) data base compiled and made available through NRCS-USDA. Digital road maps were obtained from the North Carolina Department of Transportation. We also obtained 1998 color infrared digital orthophoto-quarter quadrangles (DOQQ) that were compiled and made available by USGS and the North Carolina Center for Geographic Information & Analysis (NCCGIA).

All of the GIS coverages were converted to formats readable by ArcView GIS 3.2 (ESRI, 2003). The data were transformed to the same projection (NC State Plane 1983/meters) as needed. Overlay maps of hydrography, roads, and DOQQ were printed for use during the field trips.

Field Trips. Field trips were conducted to verify watershed boundaries, check the accuracy of the stream network and to collect information on local management practices. On the initial trip, we met with the NRCS District Conservationist and the manager of the local drainage district and obtained copies of the "as built" plans for the original drainage project and the current management plan. On a tour of the watershed, the drainage district manager assisted us in the corrections of our first estimate of the watershed boundaries. A subsequent trip was made to verify some land-uses and watershed boundaries.

Preparation of Model Inputs. The stream network was discretized using the information available in the "as built" plans for the original drainage project. These plans provided channel location, channel dimensions and channel bottom elevations. Channel dimensions and slopes have been preserved over time by a maintenance plan managed by the drainage district. The discretized network was consistent with the USGS hydrography data, but was less detailed. Some details of the USGS hydrography data were not consistent with our field observations. These inconsistencies were resolved through the assistance of Weyerhaeuser Company, a major land holder in the watershed.

The watershed was delineated into 69 fields according to general land uses (agriculture, managed forest, natural forest, and shrub land) as determined from the USGS digital ortho-quarter quads (DOQQ's) and landuse-land cover (LULC) coverage (Figure 1). Another factor considered in field delineation was the stream network. That is, the fields were delineated such that each field drained to an appropriate stream node. Field size ranged from 39 to 357 ha with an average of 161 ha (Table 1). The 69 fields were overlaid with the SSURGO soil database to determine what soil series was most representative of each field. The number of soil series and the detail of their distribution shown in the soil maps was far greater than could be reasonably treated in the model; therefore, the 16 major soils series observed on the watershed were lumped into 5 representative soil types (Figure 2). The dominant soil in a block was chosen to represent the entire block. After the distribution of the soil types, the percent coverage of each soil type in the delineated blocks did not match the percent coverage determined by the SSURGO soil map of the watershed. The differences were reconciled by changing the assigned soil types of some blocks to the soil type that represented the second greatest area.

Soil input data required by the DRAINMOD model is available from past research (Skaggs et al., 1986) for the five representative soil types. Subsurface drains had been installed on many of the agricultural fields, but detailed information about the field drainage design and the current conditions of the drains was not known. DRAINMOD simulations were used to determine drain spacings for each soil that produced reasonable yields (80% relative yield for corn), but subsurface drainage intensity was less than optimum. Therefore the drainage designs used for the watershed simulations resulted in conditions that were on average a little wetter than optimum which was considered to be a likely average condition for the agricultural lands in the watershed.

Climate Data. Hourly rainfall and daily maximum and minimum temperature data were available for Greenville, NC from the National Climate Center. These data were recorded at a station 17km from the watershed. While rainfall amounts and patterns recorded at this location are very suitable for long-term simulations, errors in the magnitude of individual storms are likely, particularly for convective storms during the summer. These errors will be reflected in the storm-by-storm comparisons between simulated and observed outflows. The temperature data were used to calculate potential evapo-transpiration by the Thornthwaite method with monthly correction factors for eastern North Carolina.

Model Simulations. The model was calibrated with the 1992-1994 flow data and 11-months of 1993 nitrate-nitrogen data. We used the 1995-1999 flow data for validation. Calibration involves determining the field parameters for DRAINMOD (such as surface storage, hydraulic conductivity) and routing variables (velocities and dispersion coefficient) to give the best fit to the observed total outflow for the three-year period. Then the model was used with the appropriate rainfall and temperature data to predict outflow for years 1995-1999 and the results were compared to measured values. For water quality, the model was calibrated for the optimum decay coefficient given the predicted flow and nitrate-nitrogen concentrations for each field in the watershed.

Input nitrogen load at the edge of each field was calculated by multiplying daily surface and subsurface flow volumes by export concentrations for surface and subsurface flow respectively. The export concentrations for nitrate-nitrogen (NO_3-N) were estimated from those reported by Deal et al. (1986) for different soils (Table 2). The mass of NO_3-N delivered to the watershed outlet from each field was determined by using the time of travel along the flow path in the first order exponential decay equation. The decay constant was assumed to be 0.2 day^{-1}. Total NO_3-N load at the watershed outlet was the sum of the delivered loads from all of the fields. Total NO_3-N loads were compared to the NO_3-N loads observed for 1993.

The calibrated model was then used to simulate the outflow and nitrate loads for a 40-year period from 1960 through 1999. Statistics quantifying the annual flow and NO_3-N load at the watershed outlet over the 40-year period were summarized. The NO_3-N predictions included the loads delivered from each field to the watershed outlet. These values were also summarized and an average delivery ratio was determined for each field. The delivery ratio for field A was calculated as the NO_3-N load delivered at the watershed outlet from field A divided by the NO_3-N load from field A deposited in the stream at the field edge. That is, a delivery ratio of 0.5 for a given field would mean that, on average, 50% of the NO_3-N leaving the field arrives at the outlet.

In addition to predicting the long-term hydrology and NO_3-N loads for the watershed for the current conditions, we conducted simulations to determine the impacts of alternative land and water management practices. The effects of land-use changes were determined through a long-term simulation using the calibrated parameters. Results were summarized in statistics and probability distributions for annual outflows and nitrogen load.

RESULTS AND DISCUSSION

Flow.

DRAINMOD-GIS simulations of the watershed predicted daily outflow rates that were similar to those measured by the USGS gauging station (Figure 3). While some of the storm peak flows did not match well, the overall shape of the hydrographs were very similar. Some differences in peak flows would be expected, since the rainfall record used for the simulation was collected 17 km from the watershed. The cumulative outflow predicted by the model was in close agreement with the measured cumulative outflow. The difference between the predicted and measured total cumulative outflow from 5/1/92 (when flow measurement began) to 8/31/99 was only 15 mm. Differences between the predicted and measured yearly cumulative totals ranged from under-prediction of 16% to over-prediction of 32% (Table 3). The high over-prediction in 1997 is somewhat misleading considering that the year has the lowest drainage outflow. Statistics of the comparison between the predicted and measured monthly flows (Table 4) indicate that the model performed well. The Nash-Sutcliffe, Pearson correlation and rank correlation coefficients were all greater than 0.70.

Nitrate-Nitrogen.

The model over-predicted nitrate-nitrogen load at the watershed outlet using the export concentration values in Table 2. The predicted cumulative load for nitrate-nitrogen at the outlet for the eleven-month period (February to December, 1993) was 32% greater than the observed cumulative nitrate-nitrogen (Table 5). Over-prediction of the cumulative load was due to high over-prediction of the load during the months of September to December as shown in Figure 4. The model predictions from February to April closely agree with the measured load. The errors in the prediction were likely due to the errors in the prediction of the outflows. Cumulative outflow from September to December was grossly over-estimated by as much as 200% (85 mm predicted compared to 29 mm measured).

Although, there may be errors in the assumed export concentrations and the decay coefficient, errors in the flow prediction may have contributed greatly to the errors in load predictions. The cumulative outflow for the eleven month period was over-predicted by 8% (258 mm compared to 238 mm). The predicted flow weighted concentration for the eleven month period was 1.14 mg/l. This is slightly higher than the measured flow weighted concentration of 0.98 mg/l.

Long-term Simulations.

Table 6 shows the summary of the statistics of the 40-yr simulation. Predicted annual outflow varied from 139 mm to 735 mm with a mean of 411 mm (standard error of 25 mm). Predicted annual NO_3-N load at the watershed outlet varied from 2.01 kg/ha/yr to 7.75 kg/ha/yr with a mean of 4.37 kg/ha/yr (standard error of 0.2). The predicted outflows and loads are distributed as shown in Figure 5 and 6. The graph shows the percentage of time that a given outflow or load will be exceeded or equaled. For example, at 90% probability, the annual outflow and load under the current condition will be greater than or equal to 232 mm and 2.98 kg/ha/yr, respectively.

Because of the in-stream losses, the predicted NO_3-N load at the watershed outlet was about 24% less than the cumulative load leaving the individual fields. This corresponds to a mean watershed delivery ratio of 76%. In-stream losses depend on the time-of-travel of the water particles as it moves from the field edge to the outlet. Thus, the NO_3-N load delivered from fields at the head of the watershed farthest from the outlet will be a smaller percentage of that leaving the field edge than that delivered from fields close to the outlet. This is indicated graphically in Figure 7 that shows that the mean delivery ratio varies from about 0.57 to 0.98 on the Chicod watershed.

Knowledge of the spatial distribution of the delivery ratio is important for decision makers. With a map of delivery ratio or delivery ratio normalized by the field load, managers can make informed decisions about locating best management practices (BMP) for reducing N losses and restoration projects within a watershed. As shown in the map of the delivery ratios, a BMP that would have the greatest impact on the outlet load could be implemented in fields near the outlet or adjacent to the main drainage canals which have the highest delivery ratios.

Table 6 and Figure 5,6 & 8 also summarizes the effects of changing land use in the watershed. From the current condition of about 50% agriculture, watershed outflow increased by 8% if the percentage of agriculture is increased to 75%. Converting all lands to agriculture increased the outflow by 14%. The changes in outflow resulted to corresponding increases in loads delivered to the outlet. Outlet load increased by 33% (75% agriculture) and 62% (100% agriculture).

Summary and Conclusions

This paper documents a case study for using a DRAINMOD based watershed scale model to predict nitrate loading from a coastal plain watershed in NC. The current, readily available database for land-use, topography, stream network, soil, and weather data was used to predict the hydrology and nitrate loading from the watershed on a day by day basis for a 40-yr period of climatological record.

The DRAINMOD-based model, which links DRAINMOD field hydrology and a spatially distributed routing model using a response function, accurately predicted the drainage volume and the cumulative nitrate-nitrogen load at the outlet of the Chicod watershed for an 8-yr period. Although there were errors in predicting the hydrograph peaks, the model accurately predicted the cumulative drainage volume. Accurate prediction of the drainage outflows is important in predicting nitrate loads. With minimal calibration for the water quality parameters, the model predicted nitrate loads at the outlet of the watershed in good agreement with the observed loads for an 11 month period of record.

The study also demonstrated the application of the model for evaluating the effects of changing land use on watershed load and outflow. An important output of the model is a graphical display of the delivery ratios for each field in the watershed. The ratio indicates the percentage of field load that is delivered to the outlet of the watershed. For management purposes, knowledge of the spatial distribution of the delivery ratios is important for determining where to implement best management practices that would have the greatest impact.

Acknowledgement

This research was supported by funds from the North Carolina Water Quality Workgroup (WRRI-Project No. 50321), the US EPA 319 program (Project No. EW9024), and the USDA NCREES/NRICGP (Project No. 98-35102-6493).

References

Amatya, D.M., G.C. Chescheir, G.P. Fernandez and R.W. Skaggs, 2003. Modeling nitrogen loading using a watershed scale DRAINMOD with an exponential decay. Trans of ASAE (in press).

Deal, S.C., J.W. Gilliam, R.W. Skaggs and K.D. Konyha, 1986, Prediction of of nitrogen and phosphorus losses related to agricultural drainage system design. Agricultural Ecosystems and Environment 18(1):37-51.

Breve, M.A., R.W. Skaggs, H. Kandil, J.E.Parsons and J.W. Gilliam. 1992. DRAINMOD-N: A nitrogen model for artificially drained lands. In Proc of the Sixth National Drainage Symposium, ASAE.

Fernandez, G.P., G.M. Chescheir, R.W. Skaggs, D.M. Amatya, F. Birgand and J.W. Gilliam. 1997. "Development and field testing of a DRAINMOD based watershed scale model", *ASAE Paper No 972194,* ASAE. St. Joseph. MI.

Fernandez, G.P., G.M. Chescheir, D.M. Amatya, and R.W. Skaggs. 2000. Uncertainty in watershed scale drainage modeling: Implications for water quality modeling. *ASAE Paper No 002095,* ASAE. St. Joseph. MI.

Fernandez, G.P., G.M. Chescheir, D.M. Amatya, R.W. Skaggs and F. Birgand. 2001. Modeling Poorly Drained Watersheds with an Integrated Watershed Scale Hydrology/Water Quality Model. *ASAE Paper No 012082,* ASAE. St. Joseph. MI.

Fernandez, G.P. G.M. Chescheir, R.W. Skaggs and D.M. Amatya. 2002. WATGIS: A GIS-Based Lumped Parameter Water Quality Model. Trans of the ASAE. Vol 45(3): 593-600.

Moussa, R. 1997. Geomorphological transfer function calculated from digital elevation models for distributed hydrological modeling. Hydrological Processes. Vol 11. 429-449.

Olivera, F. and D. Maidment. 1999. Geographic informations systems (GIS)-based spatially distributed model for runoff routing. Water Resources Research. Vol 35(4): 1155-1164.

Skaggs, R.W. 1978. A Water Management Model for Shallow Water Table Soils. Technical Report #134. Water Resources Research Institute of the University of

North Carolina, NCSU, Raleigh, N.C.
Skaggs, R.W. and A.Nassehzadeh-Tabrizi. 1986. Design drainage rates for estimating drain spacings in North Carolina. Trans of the ASAE. 29(6):1631-1640.
USDA Soil Conservation Service. 1971. Chicod Creek watershed work plan.

Table 1. Distribution of land use and soils in the Chicod watershed used in the model.

Field No	Soils	Landuse	Area , ha
1	Goldsborro	Agriculture	178.7
2	Blad	Agriculture	125.6
4	Coxville	Agriculture	164.4
5	Goldsborro	Agriculture	95.5
6	Coxville	Natural Forest	266.2
7	Goldsborro	Agriculture	191.4
8	Goldsborro	Agriculture	99.8
9	Coxville	Agriculture	129.3
10	Coxville	Natural Forest	75.0
11	Blad	Managed Forest	188.2
12	Coxville	Agriculture	197.1
13	Goldsborro	Agriculture	155.3
14	Blad	Managed Forest	246.3
15	Blad	Agriculture	88.0
16	Wagram	Managed Forest	103.9
17	Goldsborro	Agriculture	122.9
18	Rains	Managed Forest	255.7
19	Wagram	Managed Forest	155.1
20	Wagram	Agriculture	84.8
21	Rains	Agriculture	109.0
22	Rains	Agriculture	261.0
23	Blad	Managed Forest	83.6
24	Blad	Agriculture	75.5
25	Wagram	Managed Forest	108.6
26	Coxville	Agriculture	38.9
27	Rains	Managed Forest	175.4
28	Coxville	Agriculture	101.3
29	Coxville	Managed Forest	264.9
30	Blad	Agriculture	218.1
31	Blad	Managed Forest	292.7
32	Coxville	Managed Forest	306.2
33	Coxville	Managed Forest	154.8
34	Blad	Natural Forest	243.4
35	Blad	Agriculture	225.1
36	Blad	Managed Forest	165.6
37	Blad	Agriculture	156.6
38	Goldsborro	Agriculture	231.4
39	Rains	Natural Forest	357.0
40	Goldsborro	Agriculture	182.5
41	Rains	Natural Forest	212.4
42	Goldsborro	Agriculture	115.8
43	Coxville	Agriculture	130.1
44	Blad	Natural Forest	111.5
45	Goldsborro	Agriculture	204.9
46	Rains	Agriculture	116.2
47	Goldsborro	Agriculture	245.8
48	Goldsborro	Agriculture	200.8
49	Rains	Agriculture	65.6
50	Rains	Natural Forest	343.2
51	Rains	Natural Forest	142.9
52	Goldsborro	Agriculture	197.4
53	Rains	Agriculture	134.4

54	Rains	Natural Forest	60.8
55	Rains	Agriculture	138.8
56	Coxville	Agriculture	210.5
57	Goldsborro	Agriculture	106.4
58	Goldsborro	Agriculture	219.4
59	Goldsborro	Agriculture	123.5
60	Goldsborro	Agriculture	175.6
61	Goldsborro	Agriculture	151.5
62	Goldsborro	Agriculture	113.7
63	Wagram	Agriculture	109.3
64	Wagram	Managed Forest	77.4
65	Coxville	Managed Forest	236.2
66	Coxville	Natural Forest	92.8
67	Coxville	Agriculture	45.3
68	Coxville	Natural Forest	132.5
69	Coxville	Agriculture	72.1
70	Wagram	Managed Forest	174.0

Table 2. Nitrate-nitrogen export concentrations used for calibrating the model.

	Agriculture Corn - Soybean		Forest and Shrubland	
	Sub-Surface mg/l	Surface mg/l	Sub-Surface mg/l	Subsurface mg/l
Blad	2.1	0.5	0.3	0.3
Coxville	2.3	0.5	0.3	0.3
Rains	2.3	0.5	0.3	0.3
Goldsborro	2.6	0.5	0.3	0.3
Wagram	2.6	0.5	0.3	0.3

Table 3. Summary of measured and predicted annual outflows at the outlet of the Chicod watershed.

	Measured, mm	Predicted, mm	Pred. Error,%
1992	302	338	11.8
1993	389	414	6.4
1994	289	262	-8.9
1995	450	427	-5.1
1996	728	654	-10.2
1997	223	293	31.8
1998	580	614	5.9
1999	169	142	-16.4
1992-1994	979	1014	3.6
1995-1999	2150	2130	-0.9
1992-1999	3129	3144	0.5

Table 4. Summary of statistics of goodness of fit of the monthly predicted watershed outflows.

	Calibration 1992-1994	Prediction 1995-1999
Observed Mean, mm	30.6	38.4
Predicted Mean, mm	31.7	38.0
Ave Deviation, mm	0.9	-0.4
Percentage Error, %	3.6%	-0.9%
Nash-Sutcliffe	0.76	0.73
Pearson Correlation	0.90	0.86
Rank Correlation	0.71	0.84

Table 5. Summary of statistics of goodness of fit of the monthly predicted watershed load.

	Feb - Dec, 1993
Observed Mean, kg/ha	0.202
Predicted Mean, kg/ha	0.267
Ave Deviation, kg/ha	0.067
Percentage Error, %	32%
Nash-Sutcliffe	0.58
Pearson Correlation	0.83
Rank Correlation	0.32

Table 6. Summary of annual statistics of a 40-yr simulation to determine effects of controlled drainage and landuse.

	Current Condition 50% Agriculture	75% Agriculture	100% Agriculture
	Flow		
Mean, mm	411	443	468
Stand. Dev.	156	152	151
Stand. Error	25	24	24
% Difference		*7.8%*	*13.9%*
	Load		
Mean, kg/ha	4.37	5.81	7.06
Stand. Dev.	1.24	1.55	1.89
Stand. Error	0.20	0.30	0.25
% Difference		*32.9%*	*61.6%*

Figure 1. Schematic diagram of the Chicod watershed overlaid on aerial photograph (DOQQ).

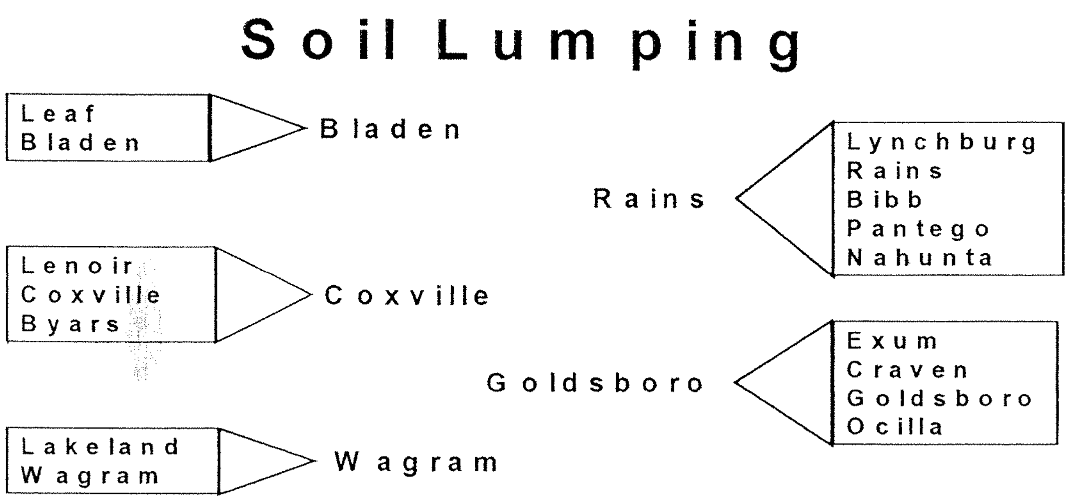

Figure 2. Soil lumping used for modeling the Chicod watershed.

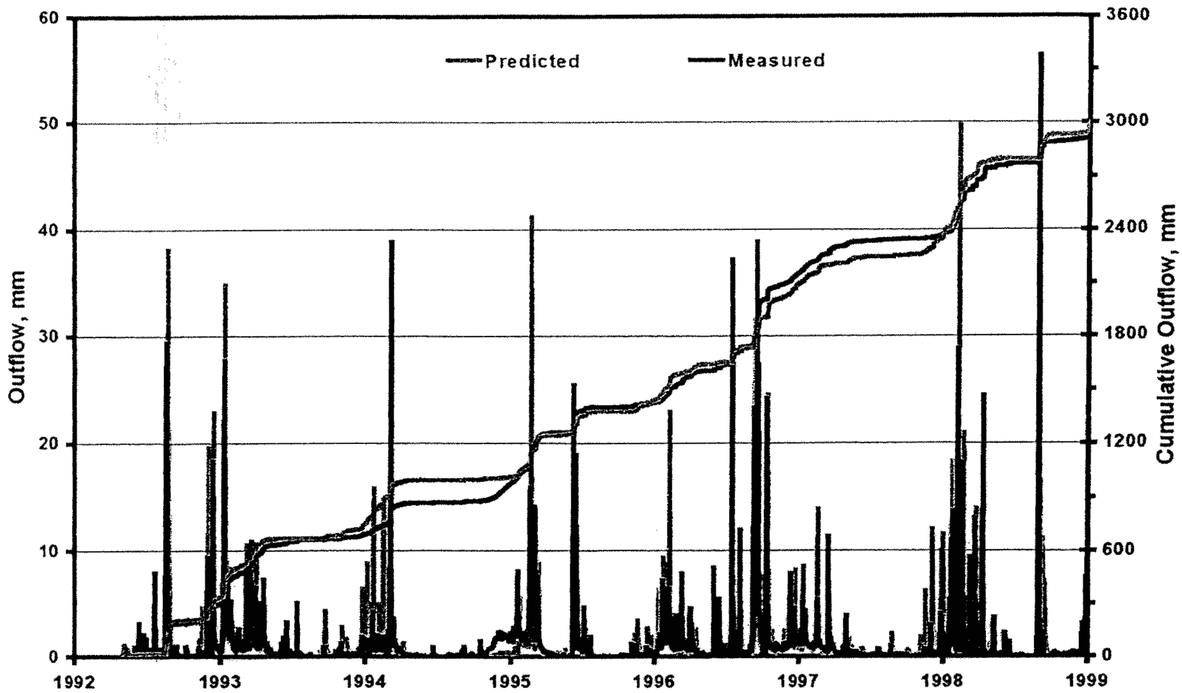

Figure 3. Predicted and measured outflows at the outlet of Chicod watershed for 1992-1999.

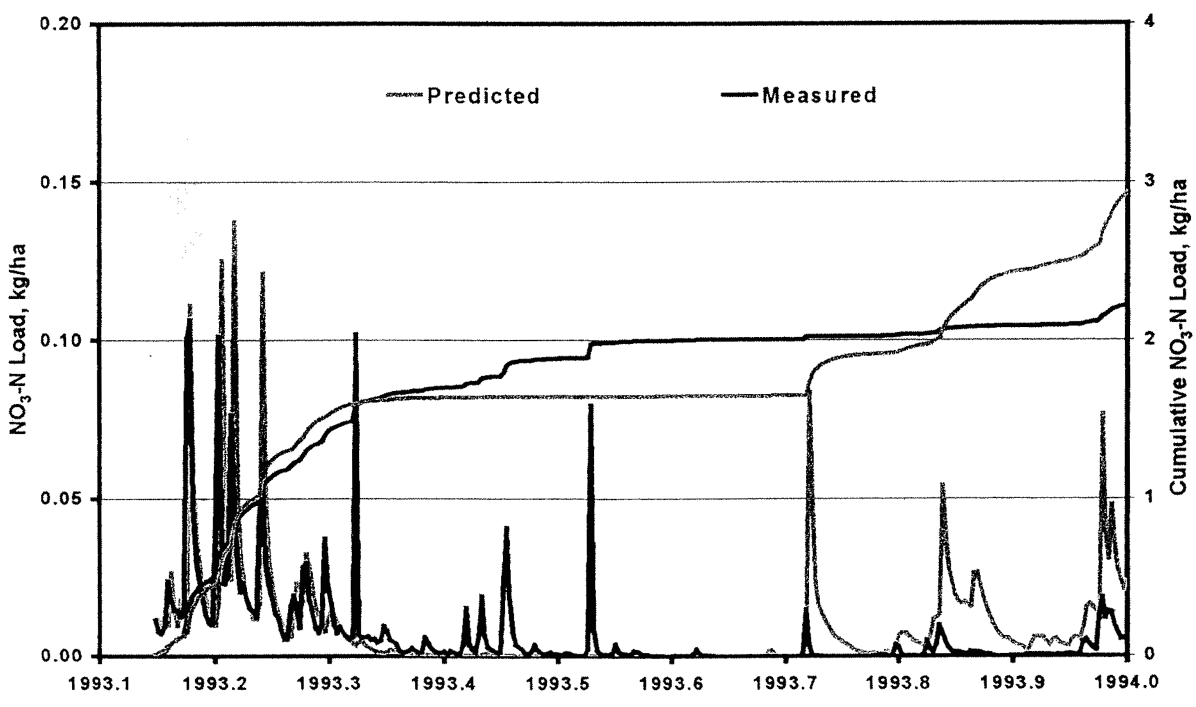

Figure 4. Predicted and measured nitrate-nitrogen load at the outlet of Chicod watershed for 1993.

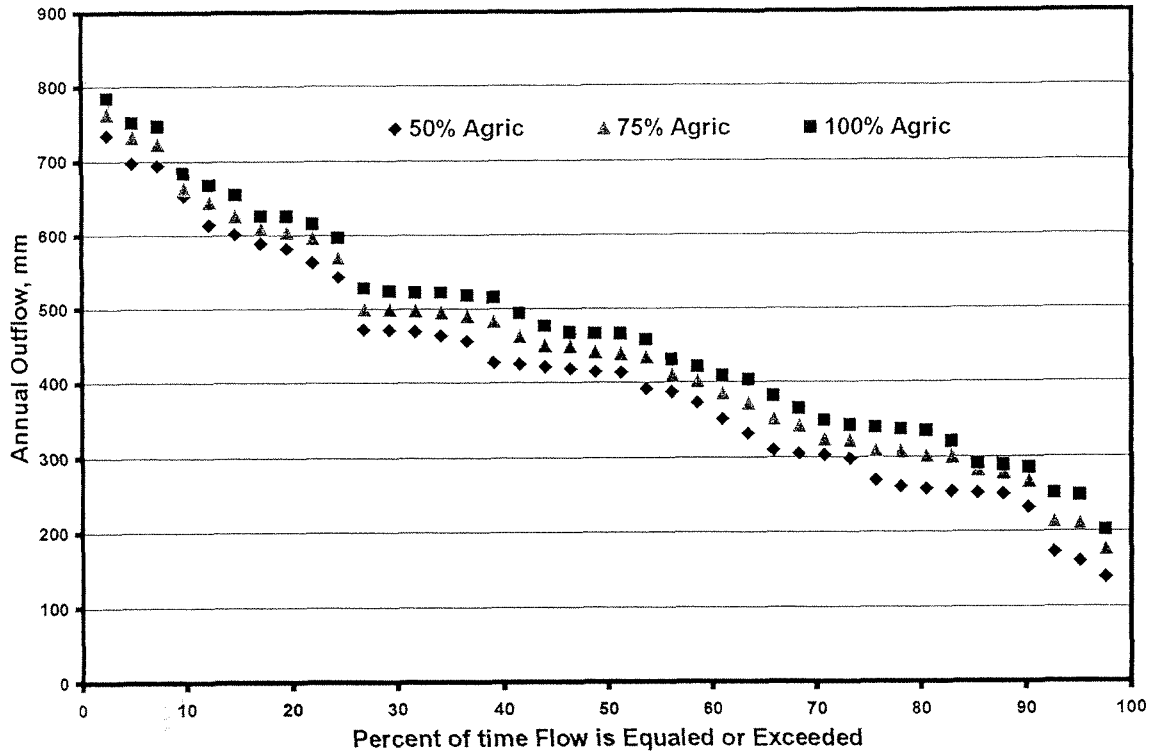

Figure 5. Distribution of annual watershed flow.

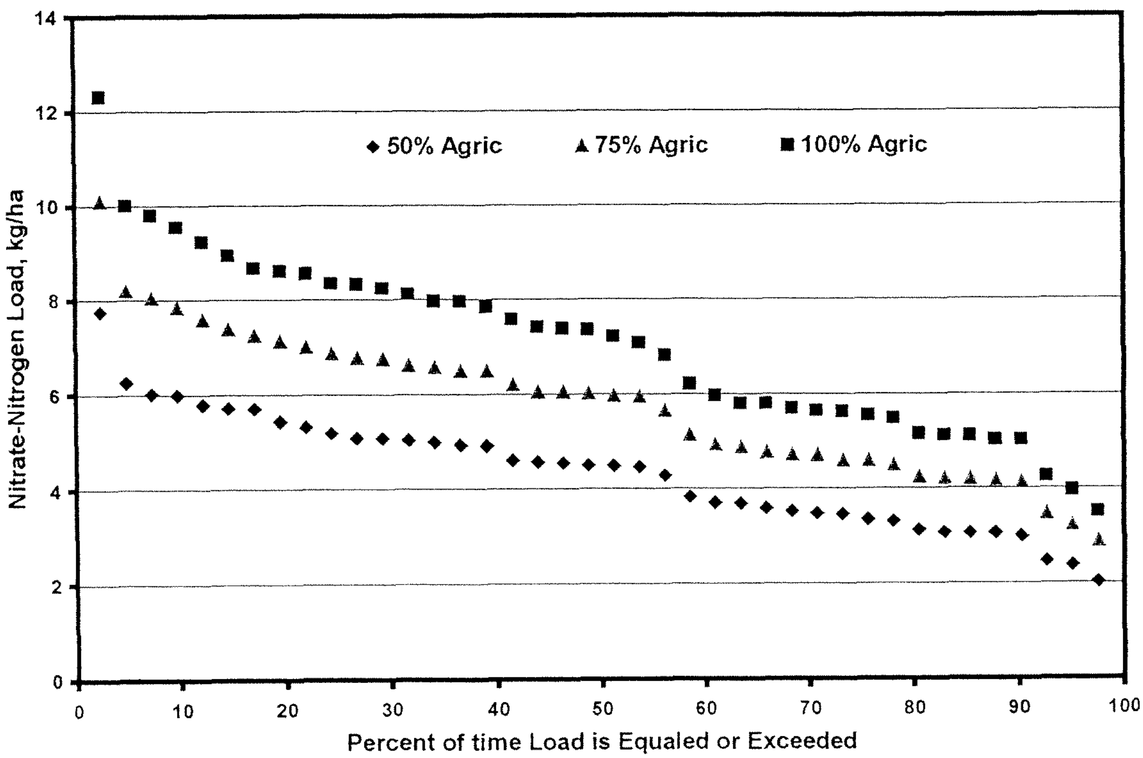

Figure 6. Distribution of annual nitrate-nitrogen load.

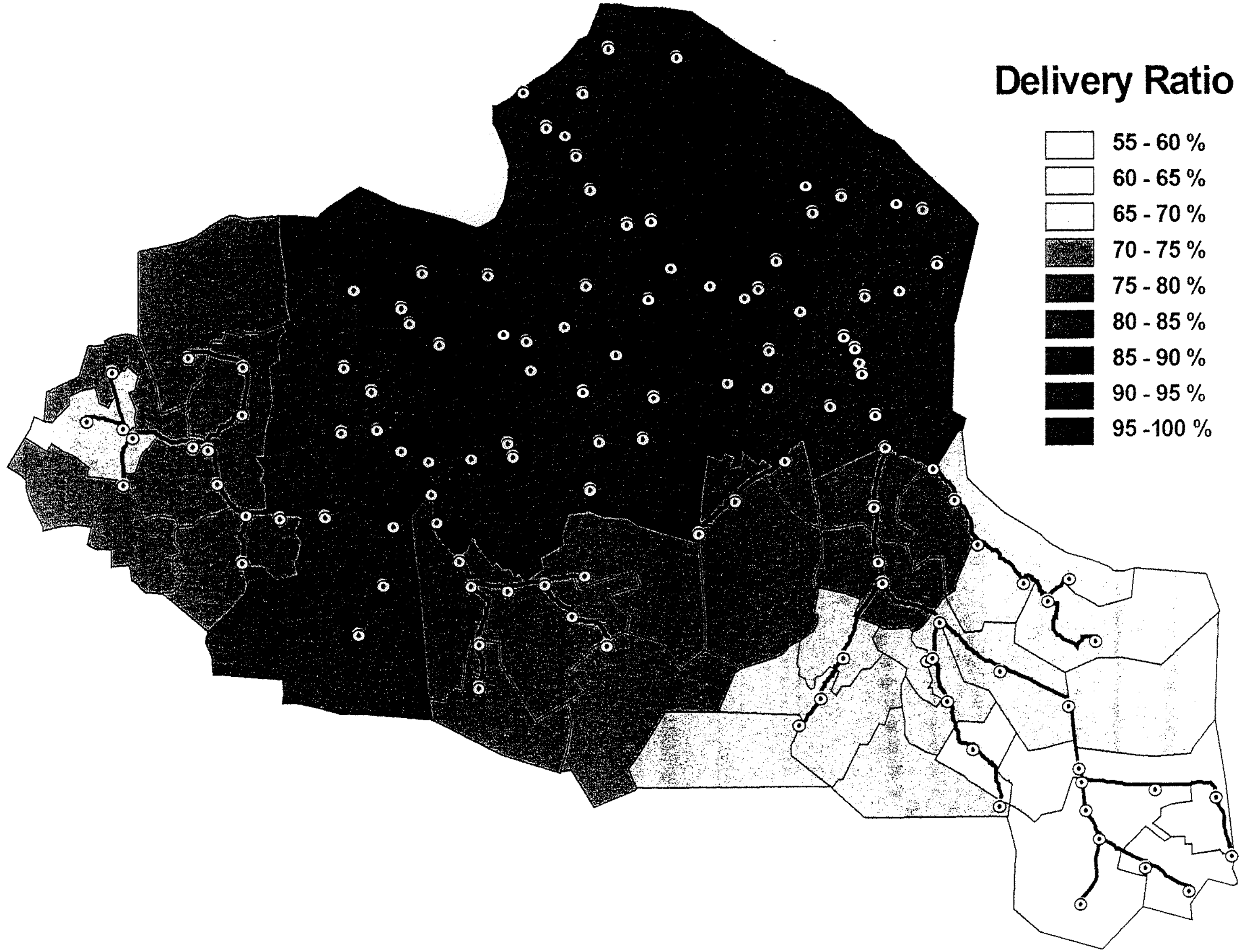

Figure 7. Distribution of delivery ratios.

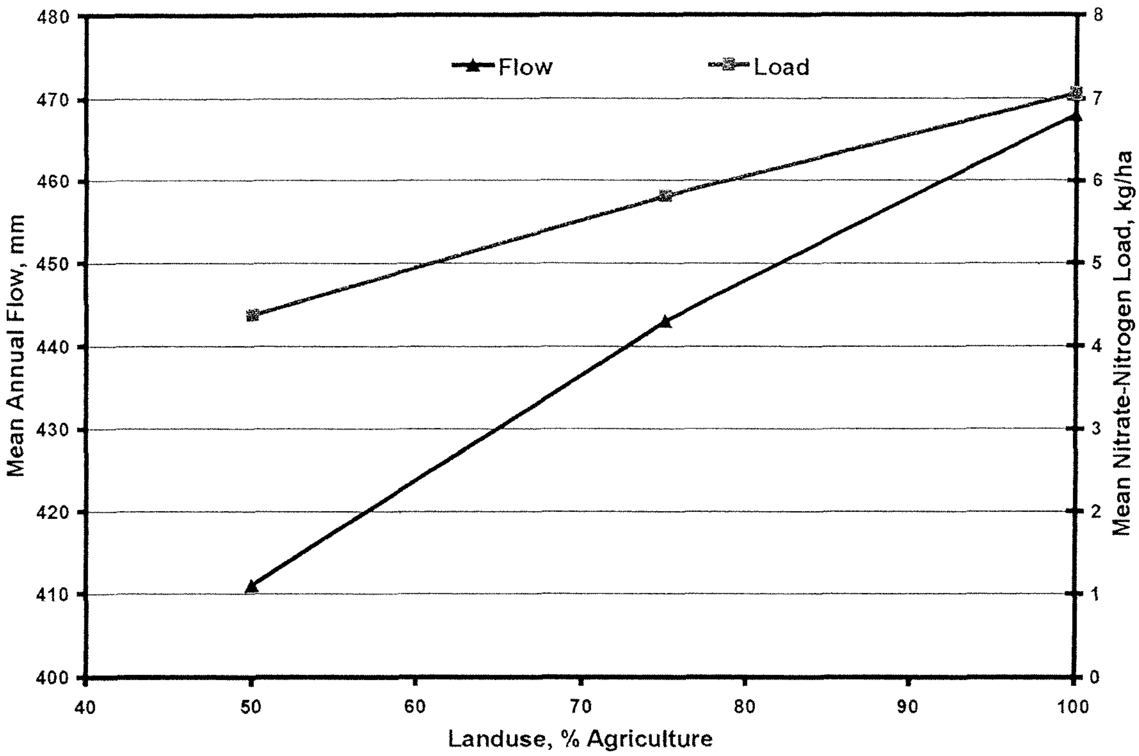

Figure 8. Effects on changing land use on watershed outflow and load.