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ESTIMATING NON-POINT POLLUTANT LOADINGS— II: A CASE STUDY IN THE FALL CREEK WATERSHED, NEW YORK*

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ABSTRACT

A geographical information-based non-point source simulation model developed in part I of this series of articles is applied to the Fall Creek Watershed in New York. The ERDAS GIS has been used to obtain spatial data for the watershed. Daily weather data from Ithaca weather station from April 1982 to March 1993 have been used. The model simulated the hydrologic and non-point source processes and produced a daily-time series of estimated non-point source pollutant loadings of Nitrogen and Phosphorus to the Cayuga Lake. Four scenarios of land-use management or regional development, viz., land-uses as they are today, all rural land-uses as idle, all rural land-uses as corn, and all rural land-uses as residential, have been analyzed and relative impact on runoff, sediment, and pollutant loadings have been compared. The results indicate that the model can serve as a tool to assess the relative impacts of different land-use management policies and regional development scenarios.

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INTRODUCTION

The Fall Creek watershed is situated in New York State, United States. A geographical information-based non-point source simulation model, CNPS has been developed in the first article in this series to estimate non-point source pollutant loadings as a function of topography, land-use, soil type, etc. [1]. The second article will present the results of a particular application of this model to the Fall Creek watershed.

DESCRIPTION OF FALL CREEK WATERSHED

Fall Creek flows into Cayuga Lake at Ithaca, New York (Figure 1). The watershed draining into Fall Creek consists of the part of the city of Ithaca and communities of Etna, Varna, Mclean, Forest Home, Virgil, Groton City, Summer Hill, Malloryville, and West Dryden. The total area of the watershed is 330 square Km, with about 60 percent lying in Tompkins county, 25 percent in Cortland county, and rest in Cayuga county. Fall Creek is approximately 48 Km long. Its mouth is situated in town of Semronius in Cayuga county. The elevation ranges from about 600 meters in the northern and eastern parts to about 380 meters at the outlet in the western part of the watershed. There are three small lakes—Dryden Lake, Lake Como, and Beebe Lake. Dryden Lake has an area of 47 ha and flows into Virgil Creek which is the main and longest tributary. Lake Como has an area of 23 ha and is located in upstream side of the creek in the town of Summer Hill. Beebe Lake is relatively small with an area of 8 ha and is situated in Cornell University campus.

The watershed lies in the cool temperature zone of continental United States. Storms are cyclonic. It receives precipitation as rainfall from September to early November. Snowfall starts during the late November and may last until March. Average annual precipitation ranges from 850 mm in Ithaca to 1000 mm in the upstream and higher elevation portions of the watershed. The monthly discharge ranges from two million cubic meters in August-September to more than forty million cubic meters in March-April. Snowmelt is an important component of stream flow during late fall and early spring months.

Except for Ithaca, all other communities are relatively small. The watershed is predominantly rural. About 50 percent of the watershed is forest and wooded. The cropland is the next large land-use.

DEVELOPING DATA FOR THE CNPS MODEL

Elevation, soil type, land-use, and watershed boundary data for Fall Creek watershed have been provided by the Cornell Laboratory of Environmental Applications of Remote Sensing (CLEARS). The spatial have been digitized using ERDAS GIS system. The geographic data implemented on ERDAS system

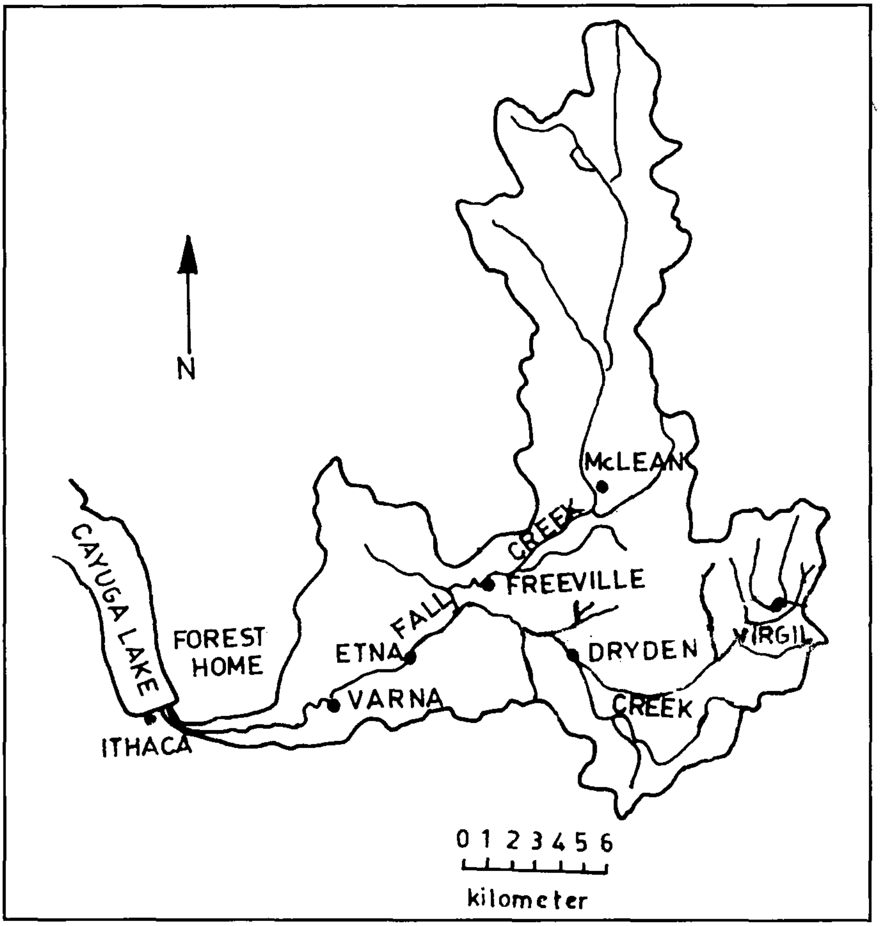

Figure 1. Outline map of Fall Creek watershed.

are further processed to derive the finished data about the land elevation, slope, soil type and land-use distribution within the watershed [2].

Elevation Data

The grid size of the raster image of the watershed is 100 meters by 100 meters representing an area of 1 hectare. There are 350 rows and 300 columns. In other words, it represents a watershed area of 35 Km in north-south direction and 30 Km in east-west direction. The elevation ranges from 115 meters to 640 meters.

Land-Use Data

The current land-use and land cover data are shown in Figure 2. There are fifteen different land-use types. Table 1 shows an inventory of land-uses for Fall Creek watershed as derived from GIS data. The land-use index serves as a key to relational land-use database.

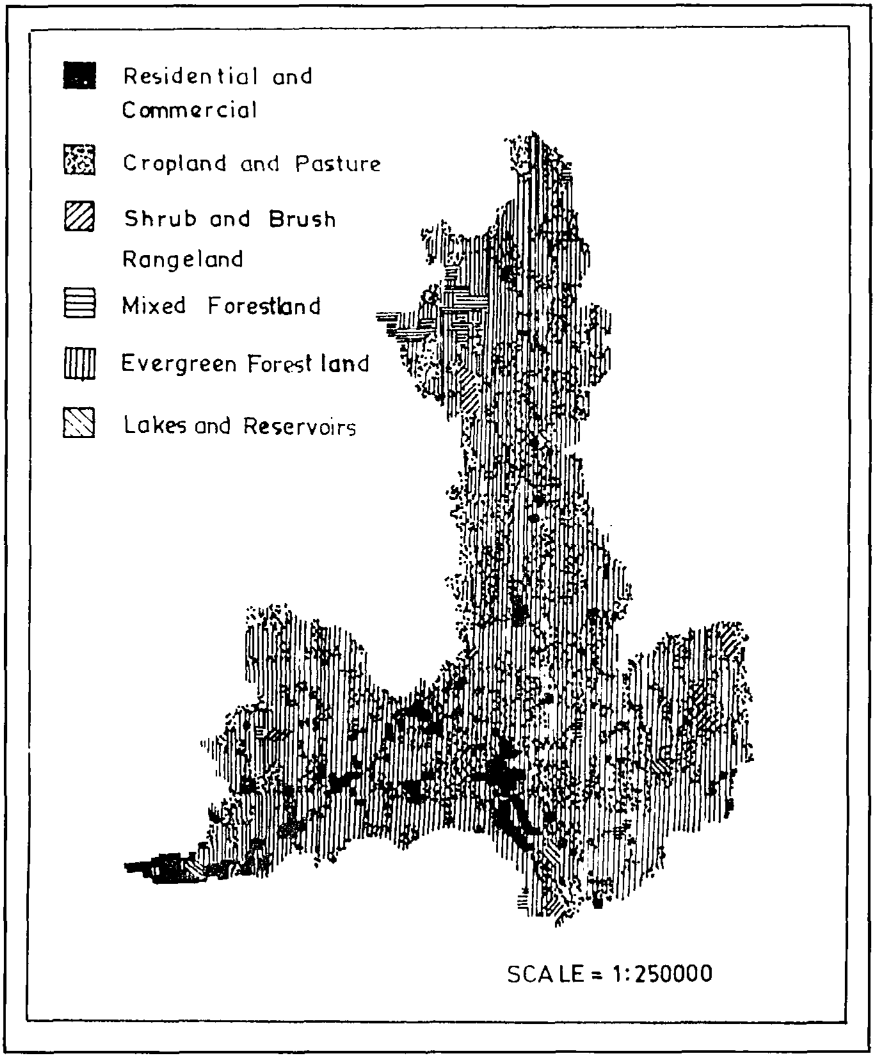

Figure 2. Land use/cover information for Fall Creek watershed.

Table 1. Present Day Land-Use/Cover Inventory of Fall Creek Watershed Derived from GIS Data

Land-Use Index	Land-Use Name	Area (Hectare)	Percentage of Total Area
1	Residential	964	2.9
2	Commercial and service	386	1.1
3	Industrial	22	0.1
4	Transitional comm. and utilities	65	0.2
5	Mixed urban/built-up	71	0.2
6	Other urban/built-up	110	0.3
7	Cropland and pasture	16331	48.6
8	Other agricultural land	40	0.1
9	Shrub and brush rangeland	233	0.7
10	Evergreen forestland	693	2.1
11	Mixed forestland	14535	43.2
12	Lakes	76	0.2
13	Reservoirs	18	0.1
14	Nonforested wetlands	29	0.1
15	Strip mines, quarries	43	0.1
	Total	33616	100.0

Soil Type Data

There are six different types of soil in the watershed. Figure 3 displays the soil distribution. Table 2 shows the soil type distribution for the area. Here soil index establishes relation to soil database.

Meteorological Data

Meteorological data have been collected from the Northeast Region Climate Center (NRCC), Cornell University. The daily time-series of temperature, precipitation, atmospheric pressure, relative humidity, and wind speed for the Ithaca weather station have been obtained. The data from April 1982 to March 1993 (11 water years) have been used to run the model.

Precipitation, temperature, and wind speed are assumed to be uniformly distributed over the watershed.

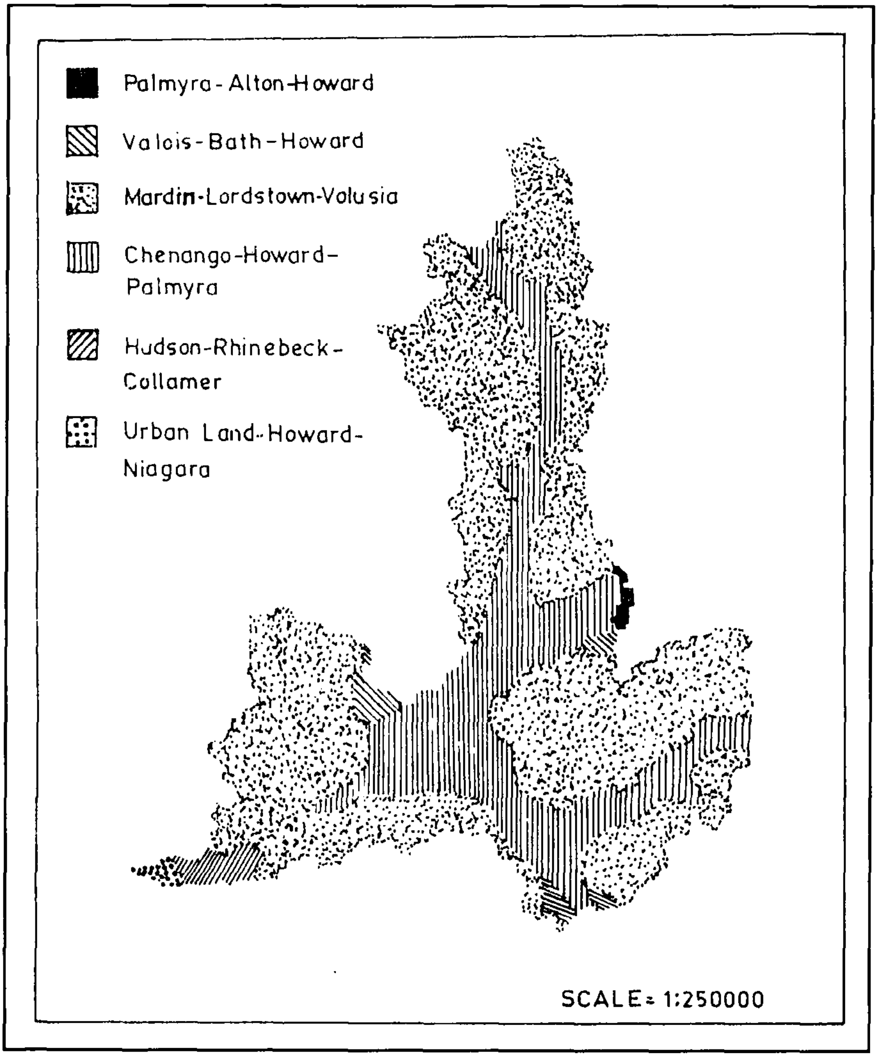

Figure 3. Soil data for Fall Creek watershed.

Land-Use Database

The parameters and properties associated with fifteen land-uses of the Fall Creek watershed have been assembled and stored in land-use database LANDUSE.DBS. Table 3 shows the specific database for the Fall Creek watershed. Each line contains land-use index, runoff curve numbers for hydrologic

Table 2. Soil Type Inventory of Fall Creek Watershed at Present as Extracted from GIS Data

Soil Index	Soil Name	Area (Hectare)	Percentage of Total Area
1	Palmyra-Alton-Howard	141	0.4
2	Valois-Bath-Howard	546	1.6
3	Mardin-Lordstown-Volusia	23792	70.8
4	Chenango-Howard-Palmyra	8527	25.4
5	Hudson-Rhinebeck-Collamer	453	1.3
6	Urban Land-Howard-Niagara	149	0.4
	Total	33616	100.0

conditions A, B, C, D respectively, land-use types, land-use name, and description for each land-use.

Soil Database

The properties and parameters of different soils are specified as SOILTYPE.DBS database. The various soil parameters of interest are wilting point, field capacity, saturated hydraulic conductivity, depth of root zone, maximum slopes at which soil is in hydrologic soil group A, B, C, and D. The specific database for the Fall Creek watershed is developed from the New York State soil survey database (Table 4).

APPLYING CNPS MODEL

The CNPS model has been implemented on a 486/33 Gateway 2000 DOS personal computer using Lahey Fortran compiler EM/32. There are two versions of the CNPS model. The normal version can load data for an area with maximum of seventy-five rows and seventy-five columns. It requires at least a 286 microprocessor with 640 K RAM. The extended memory version of CNPS_EM requires a 386 microprocessor or above with at least 8 MB of RAM. It can be used for datasets with 400 rows and 400 columns.

Estimating Non-Point Loadings

Using elevation, slope, land-use, and soil type data for Fall Creek watershed and daily weather records for Ithaca weather station from April 1982 to March 1993, the performance of the model has been evaluated. The model was run for eleven years data on a daily time-step.

Table 3. Land-Use/Cover Database

Land Use Index	Runoff Curve Number CN2				Land-Use Type	Land-Use Name	Land-Cover Description
	A	B	C	D			
1	77	85	90	92	Urban	Residential	1/8 acre lot size or less
2	89	92	94	95	Urban	Comm. & serv.	Commercial and business areas (85% impervious)
3	81	88	91	93	Urban	Industrial	Industrial districts
4	77	85	90	92	Urban	Trans comm	Transitional, commercial and utilities
5	61	75	83	87	Urban	Mixed urban	Mixed urban/built up (1/4 acre)
6	57	72	81	86	Urban	Other urban	Other urban/built up (1/3 acre)
7	68	79	86	89	Rural	Cropland pas	Cropland and pasture
8	72	81	88	91	Rural	Other agric	Other agricultural land (without conservation)
9	46	66	76	82	Rural	Rangeland	Shrub and brush rangeland
10	25	55	70	77	Rural	Evergren for	Evergreen forestland (good cover forest)
11	45	66	77	83	Rural	Mixed forest	Mixed forestland (thin, stand, poor cover)
12	100	100	100	100	Rural	Lakes	Lakes
13	100	100	100	100	Rural	Reservoirs	Reservoirs
14	25	55	70	77	Rural	NonFrst Wet.	Nonforested wetlands
15	77	85	90	92	Rural	Strip mines	Strip mines, quarries, gp

Calibrating the Model

A limited dataset of historical data was available for Fall Creek watershed. Current spatial data of Fall Creek watershed has been used to calibrate the model as spatial data corresponding to the year for which observed water quantity and quality data is available, is not readily available. Current spatial topographic and soil type data along with land-use data for the observation year have been used to calibrate the model. The calibration was done by trial and error.

Table 4. Soil Database

Soil Index	Wilt. Point (%)	Field Capacity (%)	Porosity (%)	Root Zone Depth (mm)	Sat. Hydraulic Conductivity (mm/d)	Percent Maximum Slope for Soil Group				Description of Soil
						A	B	C	D	
1	3	11	40	1000	999	3	8	15	100	Palmyra-Alton-Howard
2	8	19	40	1000	250	3	8	15	100	Valois-Bath-Howard
3	5	19	40	1000	300	3	8	15	100	Mardin-Lordstown-Volusia
4	3	11	40	1000	999	3	8	15	100	Chenango-Howard-Palmyra
5	3	27	47	1000	100	3	8	15	100	Hudson-Rhinebeck-Collamer
6	3	27	47	1000	100	3	8	15	100	Urban Land-Howard-Niagara

DISCUSSION OF MODEL OUTPUTS

The results of first year were discarded from the analyses to avoid the dependence on initial watershed conditions. It is assumed that one year is long enough to set initial data for the forthcoming years.

Output During Simulation

A graphical user interface program GRAPHICS has been developed to display the simulation results at any time step during the simulation on computer screen. In order that a user may effectively grasp and understand the watershed behavior without having to analyze huge output data results, spatially varying inputs and the model outputs can be presented as color-coded images.

File Outputs

Four different files created during the simulation are—1) estimated daily waste loadings file, 2) generated daily flow file, 3) daily sediment loadings file, and 4) summary file. The first three files could be used for further instream water quality modeling [3, 4]. The summary file lists seasonal as well as annual precipitation, runoff, dissolved, and total non-point loadings.

Post Processing of Output

No new module or program has been written for post processing of model output. Readily available commercial and powerful Microsoft Excel software has been used to import the model output and for further processing. Figures 4 and 5 show two typical time-series plots.

EFFECTS OF LAND-USE CHANGES AND/OR MANAGEMENT PRACTICES

A number of watershed management options can be analyzed by changing the current land-use distribution to determine responses to potential changes in land-uses. The following four scenarios of wastershed management/development have been explored:

case 1 - land-uses as they are today,
case 2 - all rural land-uses as corn,
case 3 - all rural land-uses as idle,
case 4 - all rural land-uses as residential.

The results for all above cases are shown in Table 5 and Figure 6.

When all agricultural land-uses are devoted for corn production, it increases potential runoff (15%), and soil erosion (2%), thereby increasing dissolved loadings in the runoff and adsorbed loadings in sediment. Thus total nitrogen and

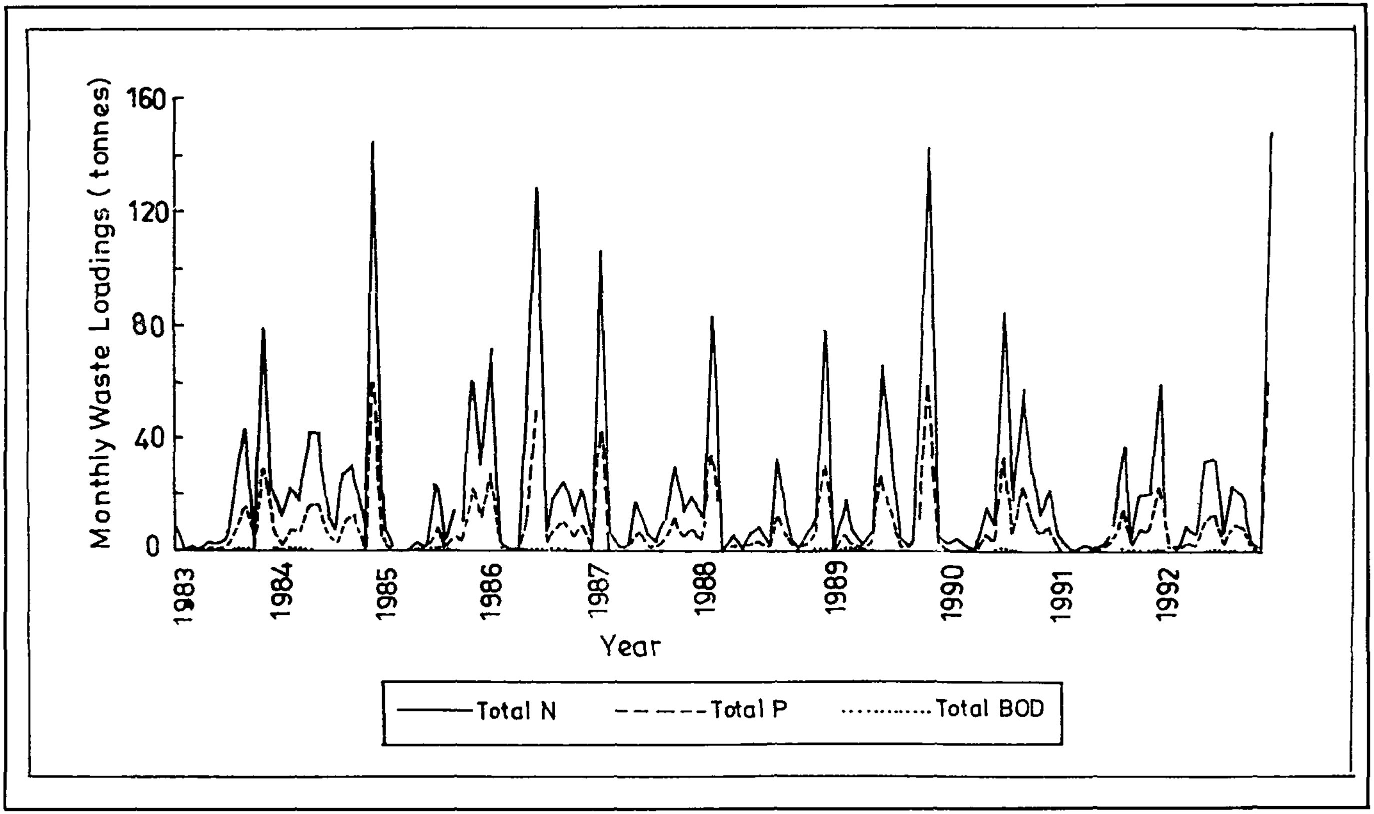

Figure 4. Time-series plot of monthly waste loadings.

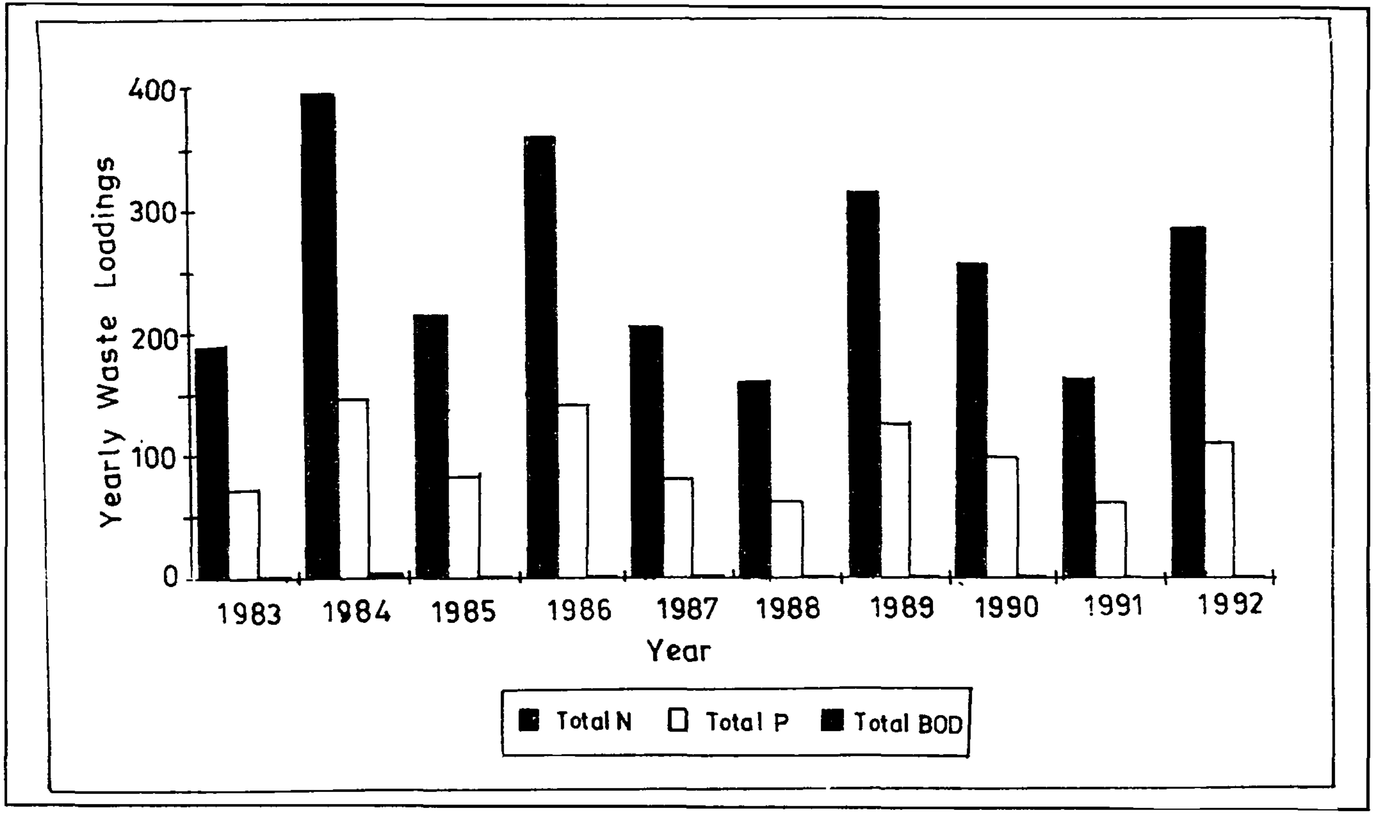

Figure 5. Time-series of annual quality constituent loadings.

Table 5. Comparison of Dissolved and Total Pollutant Loadings for Four Cases Considered

Scenario	Dissolved Nitrogen (Tonnes)	Total Nitrogen (Tonnes)	Dissolved Phosphorus (Tonnes)	Total Phosphorus (Tonnes)
1. Current state	37.29	301.98	3.29	117.50
2. All agriculture becomes corn	46.80	316.00	4.16	120.32
3. All agriculture becomes idle	5.62	28.24	0.43	9.74
4. All agriculture becomes resid.	0.87	3.03	0.04	0.24

phosphorus loadings are 5 percent and 2 percent higher as compared to current case.

It could happen that all agriculture land becomes idle. This scenario has been analyzed as case 3. In this case, runoff will reduce and so will the erosion and sediment. Total pollutant loadings will also decrease by about 90 percent.

As is expected, total nitrogen and phosphorus loadings will be almost negligible in case 4.

CONCLUSIONS

The CNPS model has been applied to a watershed situated near Cornell University in New York, United States. No new data has been collected for the current study. Using GIS data from CLEARS and weather data from NRCC, model has been run on a daily time-step for eleven years. Next land use-uses have been changed as all agriculture being 1) corn, 2) idle, or 3) urban residential. The relative impacts of potential land-use change on non-point source loadings for nitrogen and phosphorus have been explored, as compared to current land-use distribution. The total annual nitrogen and phosphorus loadings increased by 5 percent and 2 percent, respectively, in case 1), decreased by 90 percent each in case 2), and decreased by almost 100 percent each in case 3). The monthly pattern of loadings also suggests that major water quality impacts might be expected during the spring snow melt runoff as snow melt runoff carried about 15 to 20 percent of total annual loadings.

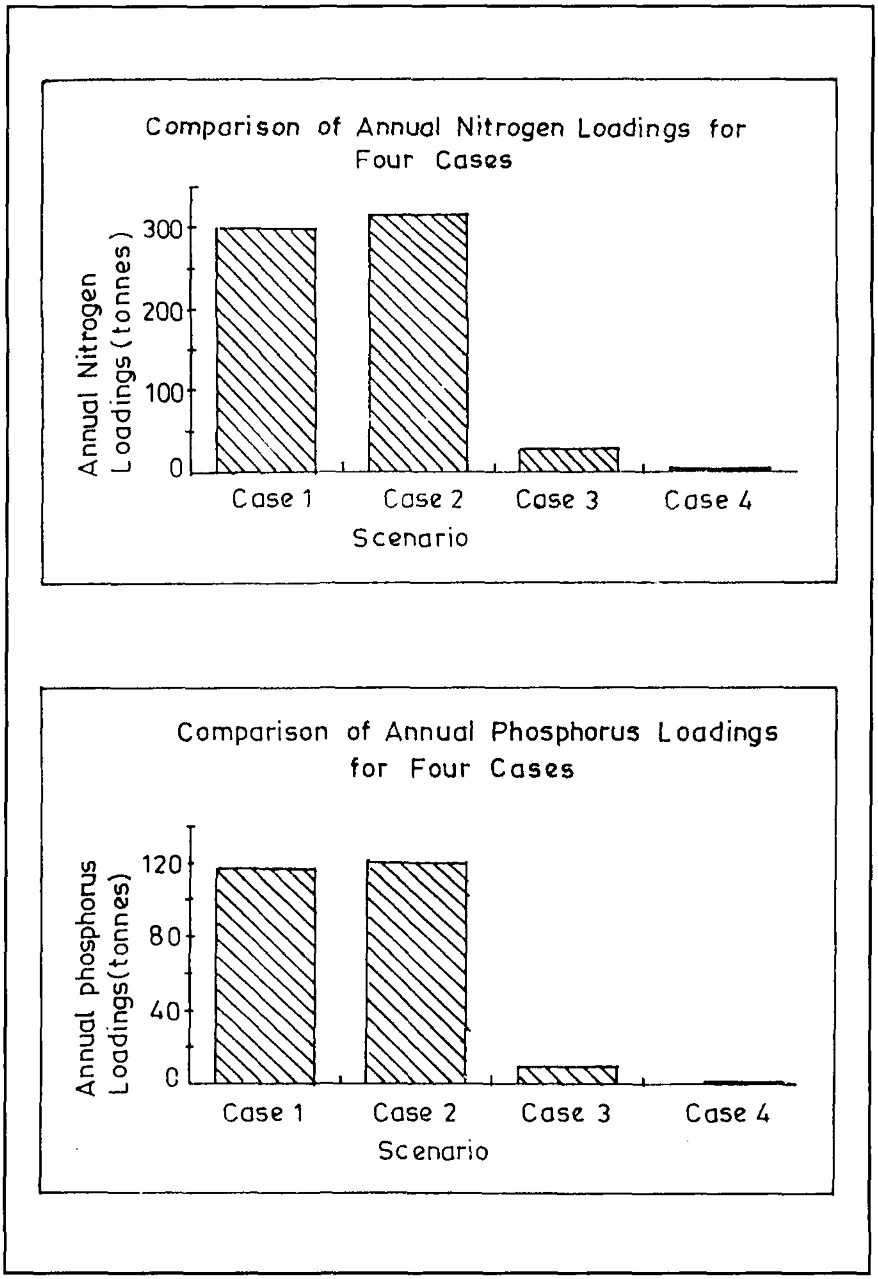

Figure 6. Comparison of annual nitrogen and phosphorus loadings for four scenarios.

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