Investigating the Impact of Best Management Practices on Nonpoint Source Pollution from Agricultural Lands

Choi , Ye Hwan * , Saied Mostaghimi**

*Dept. of Agric. Eng., College of Agric., Kangweon Nat'l University

**Dept. of Agric. Eng., Virginia Polytechnic Institute and State University, Blacksburg, Virginia, U.S.A.

Abstract □ Over the last several decades, crop production in the United States increased largely due to the extensive use of animal waste and fertilizers as plant nutrient supplements, and pesticides for crops pests and weed control. Without the application of animal waste best management, the use of animal waste can result in nonpoint source pollution from agricultural land area. In order to increase nutrient levels and decrease contamination from agricultural lands, nonpoint source pollution is responsible for water quality degradation. Nonpoint source pollutants such as animal waste, ferilizers, and pesticides are transported primarily through runoff from agricultural areas. Nutrients, primarily nitrogen and phosphorus, can be a major water quality problem because they cause eutrophic algae growth. In 1985, it was presented that Watershed/ Water Quality Monitoring for Evaluation BMP Effectiveness was implemented for Nomini Creek Watershed, located in Westmoreland County, Virginia. The watershed is predominantly agricultural and has an aerial extent of 1505 ha of land, with 43% under cropland, 54% under woodland, and 3% as homestead and roads. Rainfall data was collected at the watershed from raingages located at sites PN1 through PN 7. Streams at stations QN1 and QN2 were being measured with V-notch weirs. Water levels at the stream was measured using an FW-1 Belfort (Friez FW1). The water quality monitoring system was designed to provide comprehensive assessment of the quality of storm runoff and baseflow as influenced by changes in landuse, agronomic, and cultural practices in the watershed. As this study was concerned with the Nomini Creek Watershed, the separation of storm runoff and baseflow measured at QN1 and QN2 was given by the master depletion curve method, and the loadings of baseflow and storm runoff for TN (Total Nitrogen) and TP (Total Phosphorus) were analyzed from 1987 through 1989. The results were studied for the best management practices to reduce contamination and loss of nutrients, (e.g., total nitrogen and total phosphorus) by nonpoint source pollution from agricultural lands.

Keywords □ Best Management Practices, Nonpoint Source Pollution, Monitoring System, Separation of Baseflow and Storm Runoff, Total Nitrogen, Total Phosphorus, Loading of Nutrients or Pollutant, Master Depletion Curve Method, Contamination

I. INTRODUCTION

Until recently, all pollution diminution efforts had been aimed at controlling sewage and wastewater discharges into receiving waters. These discharges were very visible and if untreated caused obnoxious kinds of pollution : odorous anaerobic water, fishkills, and aesthetic impairment of the receiving waters during critical low-flow periods.

Nonpoint pollution, that is, pollution from storm water and runoff, was not recognized generally until the late 1960's. In many areas of the world emphasizing industrial growth, for example the United States at the beginning of this century, most obvious signs of nonpoint pollution such as smoking industrial stacks, open mine pits, and construction were considered signs of progress rather than pollution.

Engineering design practises under such conditions treated runoff and storm water as dilution of sewage that replaced sewage treatment. On the other hand, human activities such as crop and livestock production, waste water, and industrial water may contaminate (more and more) nature and agricultural lands.

Nonpoint sources of pollution account for more than 50% of the total water quality problem, and they are being recognized and investigated nationally and internationally. In many areas, nonpoint pollution, such as runoff from cropland, urban storm water, strip mining, and runoff from construction sites is becoming a major water quality problem.

The problem of nonpoint pollution involves more than the traditional pollution parameters such as suspended sediment, biochemical oxygen demand (BOD), dissolved oxygen (DO), and nutrients (nitrogen and phosphorus). In fact, some of the most serious nonpoint pollution problems do not have a parallel in the traditional point source oriented environmental pollution control area.

Water quality reflects the composition of water as affected by natural processes and by man's cultural activities, expressed in terms of measurable quantities and related to intended water use. Sources of pollution can be divided basically into two groups, natural and cultural (those caused by man). The sources can be further classified as either point or diffuse (nonpoint) sources of pollution. Nonpoint source discharges enter surface waters in a diffuse manner and at intermittent intervals that are related mostly to the occurrence of meteorological events. Nonpoint pollution also arises over an extensive area of land and is in transit overland before it reaches surface waters.

Rural nonpoint sources are especially related to agricultural activities. Agricultural pollutants have their origin in fertilizer use and pesticide application; and generally, the primary causes are agricultural methods of disturbing soils by tillage (agricultural lands) or logging (silvicultural lands). On the other hand, as urban nonpoint sources, urbanization, and related hydrologic modifications may cause increased pollution loadings that are significantly above the original or background levels.

Standard levels established by the Environmental Protection Agency insist that the fecal coliform (FC) count not to exceed 200 FC/100ml for bathing water and 14 FC/100ml for shellfish harvesting water (USEPA, 1976).

A comprehensive nonpoint source monitoring program was undertaken in 1985 to quantify the impacts of BMPs on improving runoff water quality from the Nomini Creek Watershed located in Westmoreland County, Virginia in the neighborhood of the Chesapeake Bay (Mostaghimi et al., 1989).

This study concerns the data collected from January 1987 to June 1989 at the same watershed. In this paper, the master depletion curve method was chosen for separating storm runoff and baseflow. Because these catchment areas are small watersheds, the precipitation and runoff data were recorded by monitoring systems, making it easy to analyze the baseflow and storm runoff.

The interrelation between baseflow and storm runoff is of great importance in both regional and local hydrologic investigations and a wide variety of information can be obtained by analyzing streamflow data.

Recently, a broad study on the decline of the Chesapeake Bay concluded that both point and nonpoint source pollution is responsible for water quality degradation in the Bay (EPA, 1983). In recent years, progress has been made in controlling point source pollution, while nonpoint sources, owing to their diverse and diffuse nature, have been relatively neglected. Nonpoint source pollutants are transported primarily through runoff from agricultural areas.

The purpose of this study is to describe a number of techniques that can be used to evaluate runoff to obtain a better understanding and evaluation of baseflow:

a. Separation of baseflow and storm runoff from total runoff in single and complex storms.
b. Separation of baseflow and storm runoff from total runoff in a long term such as one year including rain dates and nonrain dates.
c. To obtain the loadings of nutrient (TN and TP), contaminants and pollutants which come from nonpoint sources in baseflow and storm runoff.
d. To provide the impact of best management practices on nonpoint source pollution from agricultural lands.

II. LITERATURE REVIEW

Nonpoint source pollution is a recently significant problem and has been studied by many researchers. A key point is the development of nonpoint source pollution models, that predict runoff, soil erosion, sediment delivery, and nutrient extraction in runoff.

Taylor et al. (1971) presented that nitrogen, phosphate, and potassium concentrations were measured in streams draining woodland and farmland watersheds at Coshocton, Ohio. Temporal variations in the nutrient concentrations were much smaller than the changes in the rate of streamflow. Nutrient losses from farmland were significantly greater than those from woodland.

Timmons et al. (1973) studied nitrogen (N) and phosphorus (P) losses in the sediment and water components of surface runoff from fertilized and unfertilized plots on a Barnes loam soil located in west-central Minnesota. Simulated rainfall was used to cause surface runoff from small fallow plots that received uniform amounts of N and P but that had a different placement of the broadcast fertilizer. Jackson et al. (1973) tested a small agricultural watershed on Cowarts loamy sand in the Georgia Coastal Plains planted in corn (Zea mays L.) each year from 1969 to 1971. Surface and subsurfaces water samples were collected during each natural rainfall runoff event and NO_3-N was determined.

Römkens et al. (1973) experimented with the effect of tillage methods on the N and P composition in runoff water and runoff sediment from corn (Zea mays L.) plots in Bedford silt loam soil by applying simulated rain-storms. Schuman et al. (1973) reported that nitrogen losses from surface runoff from four field-size (30 to 60.8 ha) watersheds in southwestern Iowa, near Treynor, were measured from 1969 to 1971.

Kilmer et al. (1974) experimented with the transport of plant nutrients in drainage waters from two steeply sloping, differentially fertilized, grassed watersheds located in Western North Carolina over a 4-year period. Klausner et al. (1974) evaluated surface runoff losses of soluble nitrogen (NO_3-N, NH_4-N) and phosphorus (inorganic P) initiated by recent concerns about the discharge of plant nutrients from the agricultural sector. The animal loss of these two elements from field plots, as derived from natural rainfall, was determined.

Thomas et al. (1974) reported that eight streams draining agricultural watersheds in the important physiographic regions of Kentucky were sampled monthly from January through May in both 1971 and 1972 to determine the effects of land use and geology on the concentrations of nitrate-N and P in the stream water.

Donigian et al. (1976) demonstrated that the Nonpoint Source Pollution Loading (NPS) Model can simulate land surface contributions of nonpoint pollutants from a variety of land uses. Klausner et al. (1976) tested that the soil system in itself appeared to be an excellent disposal medium for dairy manure. The retaining efficiencies of nitrogen and phosphorus ranged from 89 to 99% for the imposed treatments for both nutrients. Haan et al. (1982) published a book used to be the hydrologic models to solve water resources problems and hydrologic rainfall models on small watersheds.

Dunigan et al. (1980) also reported that surface runoff losses of fertilizer elements from forage plots on Loring silt loam soil (5% slope) were monitored in three separate studies during an 11-month period. Incorporating approximately equal amounts of N and P from commercial ferilizer and sewage sludge did not significantly affect differences in N and P losses.

Pettyjohn (1987) reported that direct runoff and baseflow separation techniques refer to depletion curves method and chemical method.

Kenimer et al. (1989) presented a field scale model for predicting surface losses in erosion and runoff simulator accounts for pesticide losses by degradation and Volatilization washoff from vegetative soil cover, and adsorption. McCuen (1989) reported that a total runoff hydrograph consists of two parts, storm runoff and baseflow, and that the baseflow is the water discharged from extensive groundwater aquifers.

Mostaghimi et al. (1989a) reported on water quality monitoring for evaluation BMP effectiveness in Nomini Creek Watershed and Mostaghimi et al. (1989) published a paper on animal waste BMP effectiveness in Owl Run Watershed. Mostaghimi et al. (1989b) has reported that a rainfall simulator was used to study the effects of tillage system and sludge application method and rate on runoff, sediment and nitrogen (N) losses from agricultural lands.

III. MATERIALS

(1) Description of the Watershed

The Nomini Creek Watershed is located in Westmoreland County, Virginia, between the communities of Lyells, Oldsham, and Warsaw. The watershed is about 80 km northeast of Richmond, Virginia, and forms the upper ridge of the Nomini drainage basin. The Nomini Creek Watershed was selected to demonstrate the effectiveness of agricultural BMPs in reducing nonpoint source pollution over an expected 10-year period. This watershed has nonpoint source pollution problems, that is, the surface water quality has been seriously diminished (by conservation tillage to keep sediment-transported contaminants on the fields, and fertilizer management to manage nitrogen and phosphorus application rates and timing in this watershed.)

The watershed consists of two subwatersheds QN1 and QN2 with installed sampling sites, raingage sites and stream monitoring sites on the Nomini Creek Watershed (as shown Figure 1.)

The climate of Westmoreland County, Virginia, has the humidity of continental type with rather hot, humid summers, but not too severe winters, and an average annual precipitation of 101.6 cm. Among this amount, 55.9 cm (55%) usually falls in April through September, which covers the growing season for most crops. Thunderstorms occur on about 40 days each year, and most occur during the summer months. Average annual snowfall is 10 cm. The mean air temperature is 3℃ during winter months, and the summer air temperature averages 25℃. The average relative humidity is about 50% during mid-afternoon.

The soils on the watershed are generally classified as Utisols which consist of moist argillic horizons. These soils develop in areas that have long frost-free seasons, abundant rainfall, and adequate groundwater supplies. The root zone extends to a depth of 150 cm or more, and the surface and subsurface layers are very strongly acid to medium acid (pH ranging from 3.6-6.5) unless lime has been applied.

Agricultural activities in the watershed are primarily row crops with corn, soybeans, and small grains (wheat and barley) being the major crops produced.

There are 26 farms in the watershed. Among these, 33% are farmed by owners or operators and 67% are rented. Soil testing for nutrient management varies greatly between farms.

In landuse, small grain-soybean amounts to 54.3% (361.7 ha) of cropland, corn 43.2% (288.8 ha), hay 0.5% (3.7 ha), and pasture 1.8% (11.8 ha), respectively. (Landuse monitoring has the purpose of investigating the uses, disturbances, and management practices which affect water quality. Hence, parameters of particular interest include : land-use, land-use boundaries, relationship of the land-manager to the land, land disturbances, soil amendments, vegetation, and vegetation amendments.)

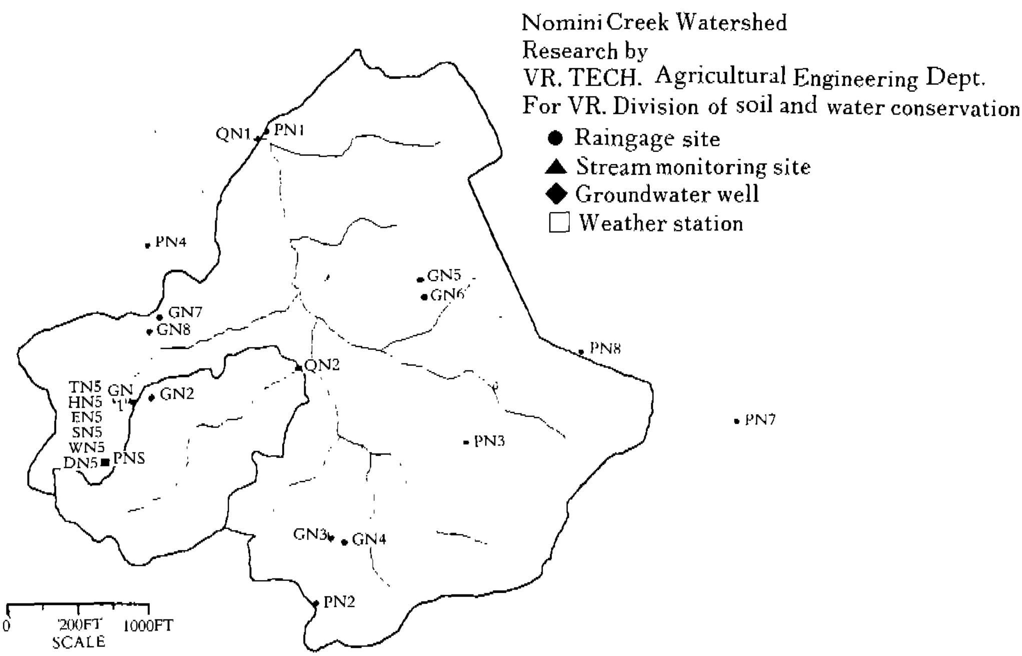

Fig. 1. Location of monitoring stations within the Nomini Creek Watershed

(2) Measuring and Monitoring Program

At QN1, the stream is measured with a 3×3m box highway culvert modified with a 5 : 1 Virginia V-notch broadcrested weir for low-flow control. Streamflow is measured with a 5 : 1 Virginia V-notch broadcrested weir modified with a rectangular sharp-crested weir over the flood plains to control very high flows at station QN2. Water level at the stations is measured using an FW-1 Belfort (Friez FW1) recorder equipped with timer gears and modified with a ten-turn potentionmeter such that stage can be sensed electronically by the Campbell Scientific 21X microloggers situated at each station.

Precipitation data is collected at the watershed from raingages located at sites PN1 through PN7. Both continuous-recording weighing raingages and tipping bucket raingages are used to measure rainfall intensity and amount. Precipitation is recorded at 2-minute intervals to the nearest 0.2mm with the tipping bucket raingages.

Sampling of surface water quality occurs at station QN1 which started in April 1985, while sampling the substation QN2 was initiated in August 1985. Streamflow conditions ranging from low to high flow rates are sampled, but special emphasis is placed on sampling high flow when storm runoff constitutes most of the streamflow.

Lists of the data collection in Nomini Creek Watershed is shown in Table 1.

Table 1. List of data collection in Nomini Creek Watershed

Parameter	Measurement method	No.Stations	Sampling frequency
Stage	Strip chart	2	continuous
	Electronic	2	1 average/10 minutes
	Hand	8	1/week
Precipitation	Strip	5	continuous
	Punch tape	2	1/5 minutes
	Electronic	6	1/minute/storm event
Water Quality	Discrete auto sampling	2	3-6mm change in stage
	Composite auto sampling	1	1/rainfall event
	Grab	2,10	2-5/storm event, 1/month

Surface water quality is being monitored at two stations, QN1 and QN2 for a few parameters. Selection of these sites was guided primarily by distribution of soils, land-use, and cultural practices in the watershed. The sampling sites were selected based on the suitability of the stream channel for accurate measurement of flow and representative sampling for water quality, as well as ease of accessibility to the sampling sites.

The data from the two sites is collected biweekly. A telephone modem attached to an IBM-PC/XT at the Blacksburg office selectively call a telephone modem attached to the 21X datalogger at each watershed site and initiates data transfer by computer software control. After transfer a pre-diagnostics program scans and displays selective information from the logger data files.

The main station, QN1, was installed at the highway bridge (BR 31-MACHADOC, USGS Quadrangle) on the main stem of Nomini Creek in April 1985 and provides runoff from a total of about 1500 ha area. Streamflow at this station appears to be influenced by marshy regions that extend from about 15 to 20m upstream of the station. These marshy conditions appear to be typical of the Virginia Coastal Plain. An additional substation, QN2, was installed in August 1985 to monitor runoff from a 225 ha subwatershed, predominantly agricultural land. Station QN2 was selected to evaluate attenuation through the natural watershed conveyance system. Furthermore, this station was established to divide to total watershed into more manageable proportions and to allow direct chemical loading comparisons between the subwatershed and the watershed as a whole.

At both stations, nutrients and sediments were the primary parameters of concern as they are suspected to be the major cause of water quality degradation in the Chesapeake Bay. (At two stations, total nutrients, N (nitrogen) and P (phosphorus) are the primary parameters of concern as they are suspected to be the major cause of water quality degradation in the Virginia Coastal Plain.) Precipitation, its quantity, intensity, and quality are important data to watershed because they are needed in order to reduce the contamination and the discharge of nutrients.

IV. METHODOLOGY

(1) Methods of Separation Storm Hydrographs

The interrelations between baseflow and storm event runoff are of great importance in both regional and local hydrologic investigations and a wide variety of information can be obtained by analyzing streamflow data. Most commonly the surface water investigator deals with stream hydrographs, channel characteristics, geomorphology, or flood routing. Many hydrologists tend to ignore the face that, at least in humid areas, baseflow accounts for a significant part of stream's total flow. Streamflow may consist of several components including baseflow, storm runoff, effluent, and precipitation that falls directly into the channel.

Thus, the discharge of baseflow into a stream is not always as simple as has been implied by Pettyjohn (1987). Baseflow enters the stream along a series of springs and seeps, issuing at the sand soil contact. During a runoff event the stream stage rises ; but, even at its peak, the state remains below the top of the soil.

In order to separate baseflow and storm runoff from the measured runoff, there are several proposed methods, that is, straight-line baseflow separation, constant slope baseflow separation, concave baseflow separation, and the master depletion curve method.

Among a few separation methods of baseflow and storm runoff, the master depletion curve method was chosen in this study.

The equation is as follows :

$$Q_b = Q_0 e^{-kt} \quad (1)$$

where Q_b : baseflow runoff at time t

Q_0 : runoff of beginning point at time t =0

k : a fitting coefficient constant

t : time (hours or days)

Separation of baseflow and storm runoff is expressed in following equation :

$$Q = Q_b + Q_s \quad (2)$$

where Q : the total runoff recorded in hydrograph (m^3/sec)

Q_b : baseflow by master depletion curve (m^3/sec)

Q_s : storm runoff (m^3/sec)

(2) Methods of Estimating Constituent Loads

In general, baseflow has a higher concentration of minerals and nutrients than that of storm runoff. During baseflow the stream's natural quality is at or near its maximum concentration of dissolved solids, but as surface runoff (or stream runoff) it reaches the channel and provides an increasing percentage of the flow, the mineral or nutrient concentration is diluted. Following the discharge peak, storm runoff diminishes, baseflow increases, and the mineral or nutrient concentration again increases. Pettyjohn (1987) has used the relation between runoff and water quality to calculate the baseflow contribution from one or more aquifers or to measure streamflow. This method of constituent loads, which requires the solution of a series of simultaneous equations, is based on the concentration of a selected chemical parameter that is characteristic of baseflow and storm runoff.

The loading equations depending on volumes are as follows :

$$V = V_b + V_s \quad (3)$$

(from eq. (2), $Q = Q_b + Q_s$)

$$CV = C_b V_b + C_s V_s \quad (4)$$

$$L_i = \Sigma^n C_i V_i^b + \Sigma^n C_i V_i^s \quad (5)$$

$$L_i = L_i^b + L_i^s \quad (6)$$

$$L = CQ \quad (7)$$

where V : total runoff (or discharge) volume (m^3)

V_b : baseflow runoff volume (m^3)

V_s : storm runoff volume (m^3)

C : total concentration (ppm)

C_b : baseflow concentration (ppm)

C_s : storm runoff concentration (ppm)
L_i : total load (mg, Kg)
L_i^b: baseflow load (mg, Kg)
L_i^s: storm runoff load (mg, Kg)

$$C_E=\frac{L_i}{V_i}=\frac{\Sigma^n C_iV_i^b}{\Sigma^n V_i^b}+\frac{\Sigma^N C_iV_i^s}{\Sigma^N V_i^s} \qquad (8)$$

where C_E : flow-weighed average concentration (ppm)
n : number of days (day)
N : number of events (No.)

C_b is determined by measuring the baseflow concentration. The quality of storm runoff, C_s is obtained from analysis of overland flow or streams at the period of peak discharge when the entire flow consists of surface runoff.

V. RESULTS AND DISCUSSION

A major impact of agricultural activites on water quality is commonly considered to be the nonpoint source contamination by nitrogen and phosphorus. Nitrogen and phosphorus concentrations in runoff from agricultual lands in Nomini Creek Watershed have been indicated as the principal source of eutrophication within the Chesapeake Bay (U.S. EPA, 1983)

The response of aquatic organisms to high nutrient concentration in runoff is the basis for the establishment of water quality criteria and standards as well as the basis for land management recommendations. The critical threshold value above which accelerated eutrophication rapidly occurs for nitrogen-limited receiving waters has been set at 0.30 mg/L of biologically available nitrogen (Bigger and Carey, 1969). To prevent the formation of biological nuisance growths in surface waters, the EPA has suggested that a concentration of 0.1 mg/L of total phosphorus not be exceeded (U.S. EPA, 1976).

This study call for an analysis of TN and TP, only, on nutrient samples collected from the Nomini Creek project. Each water (and/or soil) sample is being analyzed, in addition to TN and TP, for NH_4-N, NO_3-N, and PO_4-P.

The analyses of the nutrient data collected from the Nomini Creek Watershed are presented in the following sections.

(1) Rainfall and Runoff Separation

Rainfall and runoff responses depend on various physical and meteorological conditions in the watershed. Watersheds with similar physical characteristics respond similarly to rainfall of equal duration, magnitude, and intensity. Watershed characteristics include variables such as watershed slope, land-use, and soil infiltration characteristics.

Rainfall and runoff data collected and summarized was shown in Table 2. Rainfall, runoff, and the ratios of runoff to rainfall are given for each watershed by quarters. Due to topographic variabilities between the two watersheds (QN1 and QN2), frequency analyses on rainfall and runoff data is not possible at the present time. However, differences in runoff characteristics are apparent between the two watersheds. Runoff to rainfall ratios were consistently much higher for

Table 2. Quarterly summary of rainfall and runoff at stations QN1 and QN2

	Year	1987				1988				1989	
	Month	Jan. Feb. Mar.	Apr. May Jun.	Jul. Aug. Sep.	Oct. Nov. Dec.	Jan. Feb. Mar.	Apr. May Jun.	Jul. Aug. Sep.	Oct. Nov. Dec.	Jan. Feb. Mar.	Apr. May Jun.
Station											
QN1											
	Rainfall, mm	225	310	205	195	267	264	196	247	324	356
	Runoff, mm	61	52	30	48	52	44	25	37	49	58
	Ratio, %	27	17	15	25	20	17	13	15	15	16
QN2											
	Rainfall, mm	225	310	205	195	267	264	196	247	324	356
	Runoff, mm	121	115	86	94	98	92	75	88	96	112
	Ratio, %	54	37	42	49	37	35	38	36	30	31

QN2 than QN1. These ratios suggest that the two watersheds differ significantly in their infiltration capacities and maybe in aquifer characteristics. Whether or not these differences in runoff response are due to agricultural activities or the effect of swamps within the watershed cannot be concluded with certainty from the data collected to date.

As Table 2 indicates, the amount of rainfall was fairly uniform for the corresponding quarters of each year except for the fall quarter of 1987 and summer quarter of 1988 which were somewhat low. More rainfall occurred in the winter and spring 1989, but a higher runoff to rainfall ratio was obtained during the winter in 1987. The runoff to rainfall ratio was almost uniform except for the summer of 1988 at QN1 watershed.

Intervals between surface runoff events are generally short, and for the given season, depletion curves are plotted as a combination of several arcs of the hydrograph with the arcs overlapping in their lower parts. To plot a depletion curve, tracing paper is placed over a

Table 3. Separation of storm runoff and baseflow at QN1 and QN2 watersheds (mm)

Item		Runoff		Storm runoff		Baseflow	
Year	Mo.	QN1	QN2	QN1	QN2	QN1	QN2
	Jan.	20.45	44.84	8.39	15.80	12.06	29.04
	Feb.	18.99	37.25	8.48	10.70	10.51	26.55
	Mar.	21.19	39.24	9.32	11.81	11.87	27.43
	Apr.	20.18	39.65	9.30	11.80	10.88	27.85
	May	19.85	38.51	9.76	11.56	10.09	26.95
1987	Jun.	14.88	37.29	5.35	10.61	9.53	26.68
	Jul.	9.71	32.06	4.17	11.63	5.54	20.43
	Aug.	8.91	26.13	4.00	8.22	4.91	17.91
	Sep.	11.76	28.33	5.05	8.61	6.71	19.62
	Oct.	12.18	30.31	4.93	8.70	7.25	21.62
	Nov.	14.66	32.00	6.22	11.04	8.44	20.96
	Dec.	20.59	31.75	9.51	9.47	11.08	22.28
	Jan.	16.88	33.79	6.36	6.07	10.52	27.72
	Feb.	18.43	33.38	7.77	7.16	10.66	26.22
	Mar.	16.38	32.74	6.74	7.58	9.64	25.16
	Apr.	16.16	31.88	5.83	6.23	10.33	25.65
	May	16.64	32.34	6.51	8.54	10.13	23.80
1988	Jun.	11.25	28.89	4.90	4.38	6.35	24.51
	Jul.	8.76	26.29	3.66	6.23	5.10	20.06
	Aug.	7.73	23.93	2.88	3.54	4.85	20.39
	Sep.	8.19	25.69	3.16	5.56	5.03	20.13
	Oct.	10.44	27.35	4.01	5.29	6.43	22.06
	Nov.	14.66	31.62	6.59	7.44	8.07	24.18
	Dec.	12.23	29.14	4.25	5.11	7.98	24.03
	Jan.	13.59	30.26	5.28	7.13	8.31	23.13
	Feb.	15.39	29.41	7.37	7.79	8.02	21.62
1990	Mar.	19.82	36.35	7.76	7.82	12.06	28.53
	Apr.	21.24	38.00	7.73	9.66	13.51	28.34
	May	21.03	40.73	8.46	9.62	12.57	31.11
	Jun	15.32	33.54	6.80	8.14	8.52	25.40

hydrograph of daily flows and, using the horizontal scale with normal scale and vertical scale with log scale, the curve equations were derived as follows :

At station QN1,

$$Q = Q_0 e^{-0.03082t} \quad (9)$$

for 1987.

$$Q = Q_0 e^{-0.03249t} \quad (10)$$

for 1988.

$$Q = Q_0 e^{-0.04861t} \quad (11)$$

for 1989.

At station QN2,

$$Q = Q_0 e^{-0.02670t} \quad (12)$$

for 1987.

$$Q = Q_0 e^{-0.01137t} \quad (13)$$

for 1988.

$$Q = Q_0 e^{-0.02077t} \quad (14)$$

for 1989.

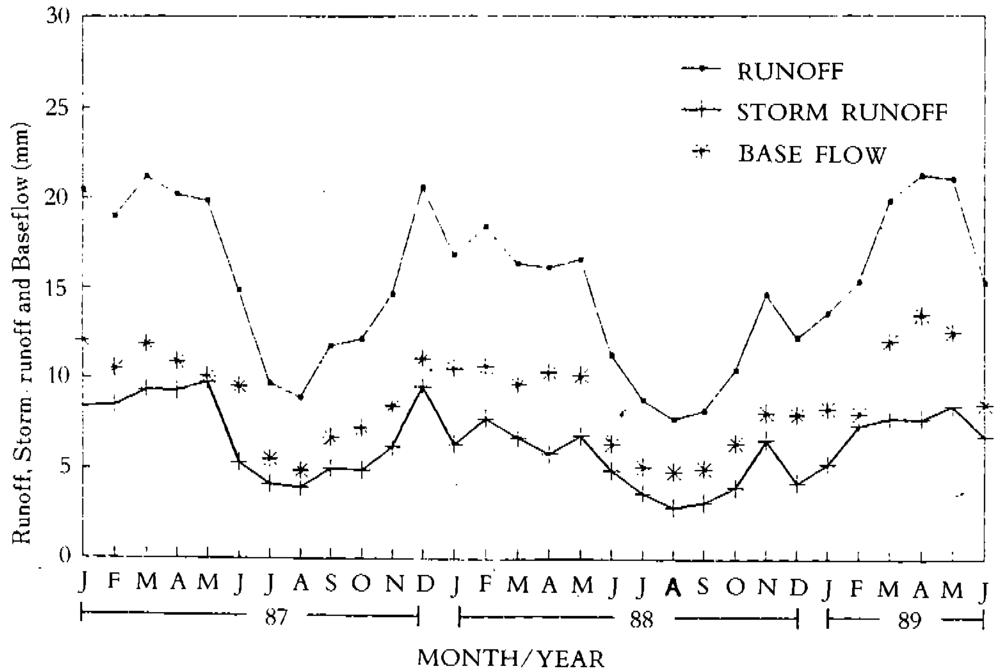

Fig. 2. Runoff separation for storm runoff and baseflow over time at QN1

Using the equations (9) through (14), the separation of storm runoff and baseflow at watersheds QN1 and QN2 as shown in Table 3 was completed. Figures 2 and 3 show the plotted values of total runoff, storm runoff and baseflow at QN1 and QN2, respectively. In Figure 2, three values such as total runoff, storm runoff and baseflow were almost parallel over time. During two and half years of QN1, peak runoff events were expressed three times in March and December 1987, and April 1989, respectively. But at QN2 as shown in Figure 3, peak runoff events were plotted at January 1987 and March and April 1989, respectively. (The whole shape was shown to become smoothly changeable.)

As Table 4 indicates, the total volume percentages of runoff with separation of storm runoff and baseflow were fairly uniform in both watersheds. The volume percentage of storm runoff and baseflow in the QN1 watershed averaged 44% and 56% respectively. In QN2 watershed, these values averaged 25% and 75%, respectively. As a result, the percentages of baseflow volume were all higher than those of storm runoff volume in both the QN1 and QN2 watersheds.

Table 4. Total volume of storm runoff and baseflow

Year	Watershed QN1(1505 ha) Item	Volume (×10"1)	%	QN2(225ha) Item	Volume (×10"1)	%
1987	stomy runoff	1,265.56	43.70	stomy runoff	293.39	31.14
	baseflow	1,630.57	56.30	baseflow	646.51	68.86
	total	2,896.13	100.00	total	938.90	100.00
1988	stomy runoff	938.49	39.65	stomy runoff	164.40	20.51
	baseflow	1,424.41	60.35	baseflow	637.30	79.49
	total	2,362.90	100.00	total	801.70	100.00
1989 (Jan.-Jun.)	stomy runoff	67.49	44.26	stomy runoff	12.20	25.31
	baseflow	85.01	55.74	baseflow	36.00	74.69
	total	152.50	100.00	total	48.20	100.00

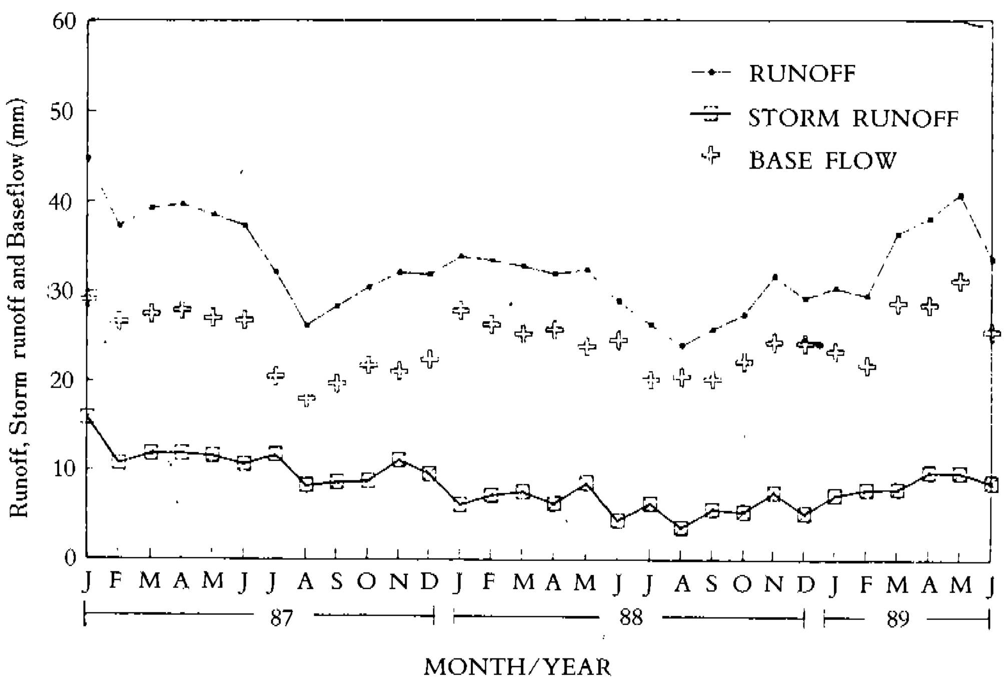

Fig. 3. Runoff separation for storm runoff and baseflow over time at QN2

The differences in runoff characteristics means apparently a physical and hydrological phenomena occured between the two watersheds. This suggests that the two watersheds differ significantly in their infiltration capacities and aquifer characteristics and agricultural activities, that is, and use, agronomic, and cultural practices.

(2) Rainfall Water Quality

Analyzing the rain water quality during the given period, the results were shown as Table 5 and Figure 4. The concentration of nitrogen (N) in the rainwater ranged from 1.056 to 8.195 mg/L (ppm) and peak values were expressed twice as 8.009 mg/L in March and 8.195 mg/L in July 1988, respectively.

Table 5. Mean monthly rain water quality data for Nomini Creek Watershed(ppm)

Yr.	Mo.	Item TN	Item TP	Yr.	Mo.	Item TN	Item TP
1987	Jan.	3.656	0.354	1988	Apr.	4.559	0.628
	Feb.	2.856	0.262		May	2.655	0.542
	Mar.	4.095	0.480		Jun.	4.473	0.079
	Apr.	3.900	0.321		Jul.	8.195	1.754
	May	3.317	0.197		Aug.	5.604	0.293
	Jun.	2.831	0.212		Sep.	1.229	0.377
	Jul.	2.612	0.221		Oct.	1.668	0.000
	Aug.	2.392	0.229		Nov.	1.469	0.029
	Sep.	3.729	0.242		Dec.	3.373	0.000
	Oct.	1.394	0.540	1989	Jan.	1.201	0.118
	Nov.	1.875	0.576		Feb.	1.560	0.149
	Dec.	2.558	0.531		Mar.	1.946	0.166
1988	Jan.	4.224	1.307		Apr.	3.446	0.252
	Feb.	4.564	8.762		May	1.529	0.000
	Mar.	8.009	0.451		Jun.	1.056	0.107

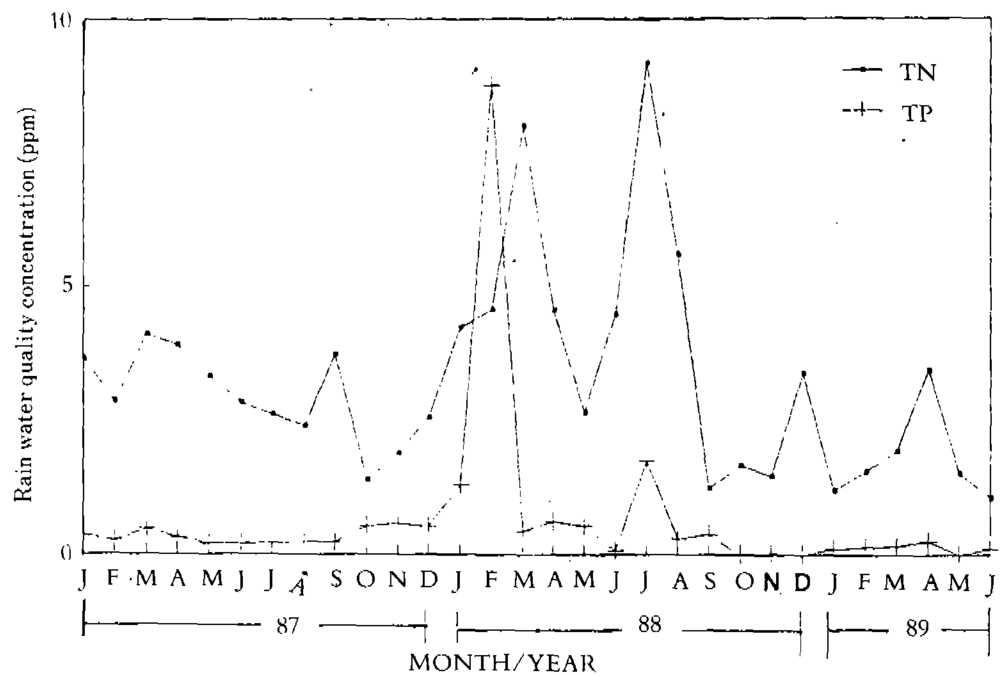

Fig. 4. Mean monthly rain water quality over time

But the peak phosphorus (P) concentration was shown to be 8.762 mg/L in February 1988, while the other whole values were comparatively low. Average rainwater quality during the given period was 3.199 mg/L of TN and 0.639 mg/L of TP, respectively.

(3) TN and TP Loadings from Storm Runoff

As shown in Table 6 and in Figure 5, monthly losses of TN at watersheds QN1 and QN2 ranged from 32.56 g/ha to 853.23 g/ha and from 68.18 g/ha to 3433.87 g/ha, respectively.

Maximum peak loss of nitrogen was 3.4 kg/ha at QN2 watershed in January 1987, while peak losses at QN1 were 648.79 and 788.78 g/ha in January and May 1988, and 853.23 g/ha in March 1989. At QN2, peak losses of TN were 706.76 g/ha in July 1987 and 844.93 in January 1988. At the other time intervals, the losses of TN varied in similar patterns at QN1 and QN2.

The annual rate of nitrogen loss was 3.0 kg/ha, 3.5 kg/ha and 2.5 kg/ha in 1987, 1988, and 1989, at QN1. At QN2, the values were 11.2 kg/ha, 4.3 kg/ha, and 2.0 kg/ha, respectively. Most loss values were higher at QN2 than QN1 and were similar to the former report which Mostaghimi (1989) researched.

Table 6. Monthly TN loading from QN1 and QN2 (g/ha)

Yr.	Mo.	Watershed QN1	Watershed QN2	Yr.	Mo.	Watershed QN1	Watershed QN2
	Jan.	298.41	3433.87		Apr.	478.21	474.20
	Feb.	134.07	2124.00		May.	788.78	579.73
	Mar.	59.77	1263.16		Jun.	217.62	359.56
	Apr.	554.54	652.27		Jul.	121.15	489.92
	May.	525.78	370.49	1988	Aug.	314.83	144.58
1987	Jun.	246.74	636.71		Sep.	74.52	161.48
	Jul.	51.89	706.76		Oct.	116.60	357.87
	Aug.	32.56	159.20		Nov.	164.97	185.28
	Sep.	292.50	429.47		Dec.	41.87	68.18
	Oct.	127.88	351.16		Jan.	145.47	271.35
	Nov.	219.84	550.93		Feb.	287.00	269.35
	Dec.	424.52	519.64	1989	Mar.	853.23	106.33
	Jan.	648.79	844.93		Apr.	275.97	380.10
1989	Feb.	345.47	429.73		May.	221.10	490.20
	Mar.	184.07	205.07		JUn.	713.23	437.85

As shown in Table 7 and in Figure 6, monthly losses of TP at watersheds QN1 and QN2 ranged from 0.68 g/ha to 46.06 g/ha and from 1.07 g/ha to 189.02 g/ha, respectively.

Maximum peak loss of phosphorus was recorded as 0.19 kg/ha at the QN2 watershed. The shape of the other time was expressed in similar type with QN1 and QN2.

Annual losses of phosphorus at QN1 were 0.2 kg/ha, 0.13 kg/ha, and 0.14 kg/ha in 1987, 1988, and 1989, and at QN2, 0.69 kg/ha, 0.15 kg/ha, and 0.12 kg/ha, respectively.

The losses were higher at QN2 than QN1. These results show that the subwatershed located above QN2 is responsible for a significant portion of nonpoint source pollution in the watershed. Preliminary results suggest that BMP implementations should be intensified on this point of Nomini Creek Watershed and the results were similar to former reports which Mostaghimi (1989) researched.

(4) TN and TP Loadings from Baseflow

As shown in Tables 8 and 9 and in Figures 7 and 8, the mean monthly loading of TN and TP at QN1 and QN2 ranged from 100.6 g/ha to 1095.26 g/ha and from 0.91 g/ha to 467.35 g/

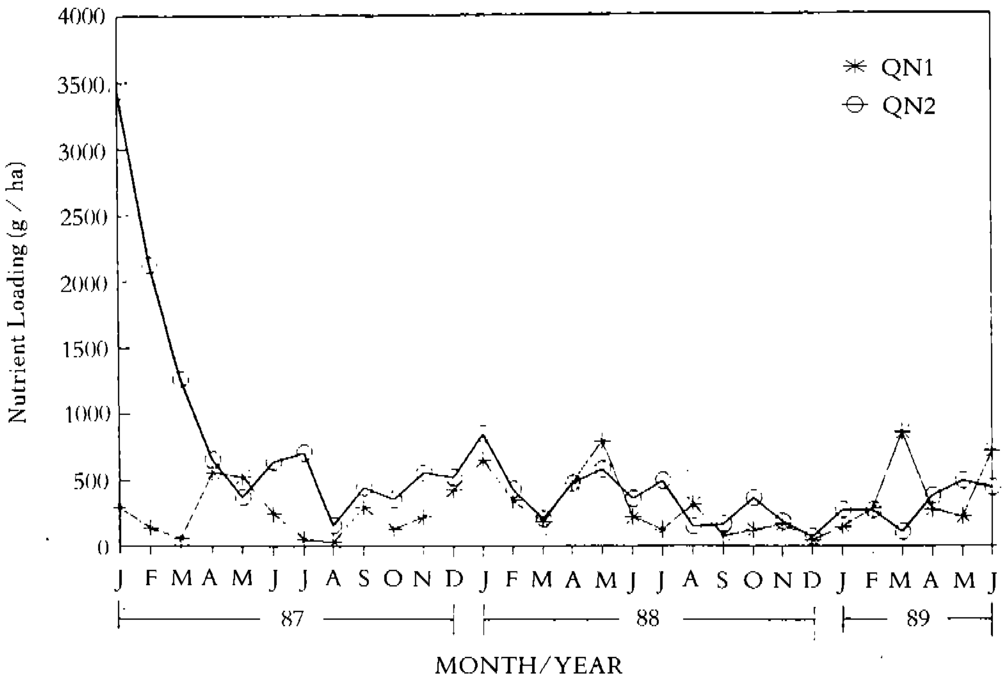

Fig. 5. Monthly TN losses from QN1 and QN2

Table 7. Monthly TP loading from QN1 and QN2 (g/ha)

		Watershed				Watershed	
Yr.	Mo.	QN1	QN2	Yr.	Mo.	QN1	QN2
	Jan.	7.13	166.49		Apr.	11.85	7.20
	Feb.	12.84	189.02		May.	11.47	3.11
	Mar.	4.37	91.64		Jun.	4.60	2.04
	Apr.	30.93	40.62		Jul.	25.24	31.92
	May	24.60	12.04		Aug.	13.39	8.80
	Jun.	29.00	94.09		Sep.	0.68	5.12
	Jul.	1.86	16.18		Oct.	10.20	19.59
	Aug.	1.19	4.36		Nov.	21.15	45.87
	Sep.	8.80	8.62		Dec.	2.62	4.76
	Oct.	6.69	10.13		Jan.	23.61	23.52
	Nov.	30.30	28.22		Feb.	4.50	5.10
	Dec.	43.10	33.16		Mar.	46.06	23.52
	Jan.	11.84	8.00		Apr.	38.46	12.84
	Feb.	5.50	1.07		May	6 .30	43.14
	Mar.	6.56	7.96		Jun	20.37	14.70

Table 8. Mean monthly nutrient loading from baseflow of QN1

Yr.	Mo.	conc.TN (mg/L)	conc.TP (mg/L)	Item baseflow (cm)	TN loading (g/ha)	TP loading (g/ha)
	Jan.	5.221	0.421	1.206	629.65	50.77
	Feb.	5.776	0.613	1.051	607.06	64.43
	Mar.	5.264	0.607	1.187	624.84	72.05
	Apr.	5.437	0.439	1.088	591.55	47.76
	May	3.959	0.383	1.009	399.46	38.64
1987	Jun.	2.724	0.429	0.953	259.60	40.88
	Jul.	3.415	0.296	0.554	189.19	16.40
	Aug.	3.780	0.804	0.491	185.60	39.48
	Sep.	4.425	6.965	0.671	296.92	467.35
	Oct.	4.452	0.837	0.725	322.77	60.68
	Nov.	3.340	0.938	0.844	281.90	79.17
	Dec.	3.848	0.813	1.108	426.36	90.08
	Jan.	8.286	0.749	1.052	871.69	78.79
	Feb.	5.330	1.207	1.066	568.18	128.67
	Mar.	3.516	0.465	0.964	338.94	44.83
	Apr.	8.529	0.628	1.033	881.05	62.80
	May	10.812	0.618	1.013	1095.26	62.60
1988	Jun.	4.591	0.494	0.635	291.53	31.37
	Jul.	4.267	0.964	0.510	217.62	49.16
	Aug.	14.176	0.603	0.485	687.54	29.25
	Sep.	2.000	0.018	0.503	100.60	0.91
	Oct.	2.224	0.193	0.643	143.00	12.41
	Nov.	3.014	0.398	0.807	243.23	32.12
	Dec.	2.850	0.185	0.798	227.43	14.76
	Jan.	3.809	0.612	0.831	316.53	50.86
	Feb.	3.645	0.024	0.802	292.33	1.92
1989	Mar.	8.913	0.327	1.206	1074.91	39.44
	Apr.	3.600	0.434	1.351	486.36	58.63
	May	2.739	0.082	1.257	344.29	10.31
	Jun.	11.959	0.299	0.852	1018.91	25.47

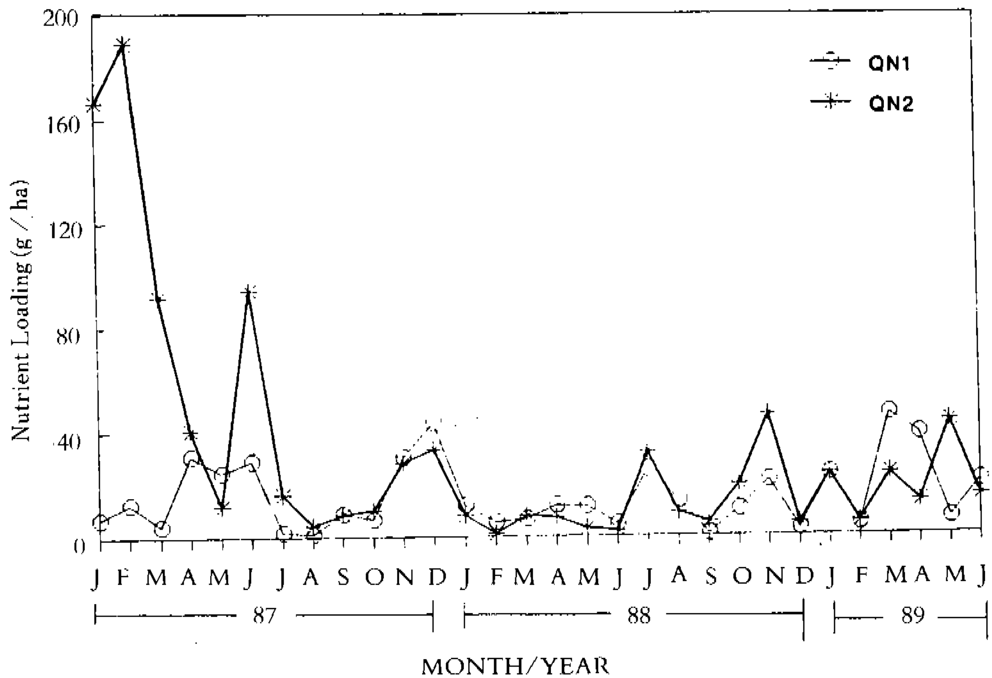

Fig. 6. Monthly losses of TP from QN1 and QN2

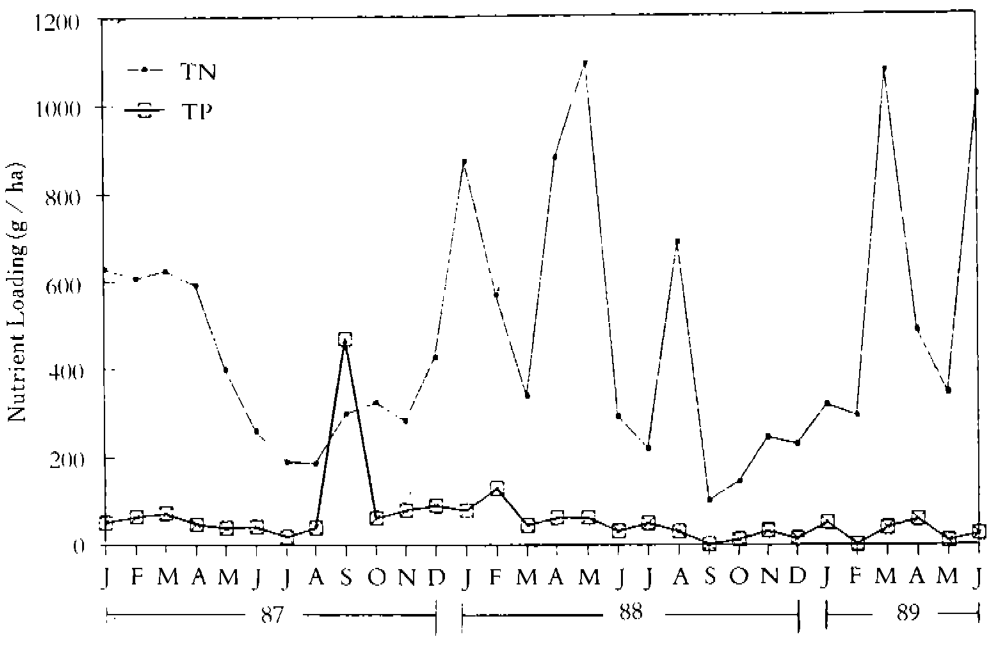

Fig. 7. Mean monthly losses of TN and TP from baseflow of QN1

Table 9. Mean monthly nutrient loadings from baseflow of QN2

Yr.	Mo.	conc.TN (mg/L)	conc.TP (mg/L)	Item baseflow (cm)	TN loading (g/ha)	TP loading (g/ha)
	Jan.	12.411	0.547	2.904	3604.15	158.85
	Feb.	6.116	0.741	2.655	1623.80	196.74
	Mar.	5.070	0.738	2.743	1390.70	202.43
	Apr.	5.481	0.627	2.785	1526.46	174.62
	May	4.040	0.316	2.695	1088.78	85.16
1987	Jun.	3.331	0.882	2.668	888.71	235.32
	Jul.	7.465	0.681	2.043	1525.10	139.13
	Aug.	5.883	0.669	1.791	1053.65	119.82
	Sep.	6.887	3.336	1.962	1351.23	654.52
	Oct.	8.507	10.484	2.162	1839.21	2266.64
	Nov.	8.391	1.083	2.096	1758.75	227.00
	Dec.	8.353	1.434	2.228	1861.05	319.50
	Jan.	10.711	0.093	2.772	2969.09	25.78
	Feb.	5.597	0.014	2.622	1467.53	3.67
	Mar.	3.767	0.130	2.516	947.78	32.71
	Apr.	9.746	0.158	2.565	2499.85	40.53
	May	7.942	0.048	2.380	1890.20	11.42
1988	Jun.	8.148	0.050	2.245	1997.07	12.26
	Jul.	10.653	0.711	2.006	2136.99	142.63
	Aug.	7.053	0.426	2.039	1438.11	86.86
	Sep.	2.902	0.100	2.013	584.17	20.13
	Oct.	5.986	0.319	2.206	1320.51	70.37
	Nov.	3.252	0.916	2.418	786.33	221.89
	Dec.	3.765	0.238	2.403	904.73	57.19
	Jan.	5.242	0.461	2.313	1212.47	46.10
	Feb.	2.955	0.024	2.162	638.87	5.19
1989	Mar.	8.139	0.198	2.853	2322.06	56.49
	Apr.	4.817	0.167	2.834	1365.14	47.33
	May	4.860	0.427	3.111	1511.95	132.84
	Jun.	6.214	0.195	2.540	1578.36	49.53

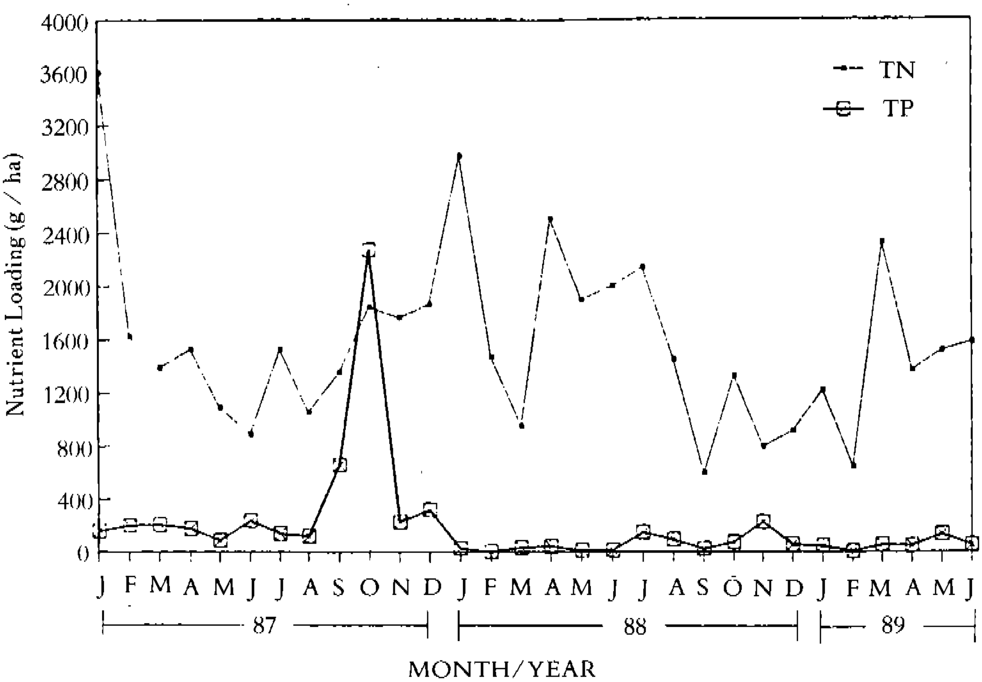

Fig. 8. Mean monthly losses of TN and TP from baseflow of QN2

ha. It also ranged from 584.19 g/ha to 3604.15 g/ha and from 3.67 g/ha to 2266.64 g/ha, respectively.

Peak loadings of TN at QN1 were 871.69, 1095.26, 1074.91 and 1018.91 g/ha in January and May, 1988, and March and July, 1989, respectively. Peak loading of TP at QN1 was 467.35 g/ha in September 1987.

But at QN2, peak loadings of TN were 3604.15, 2969.85, 2499.85 and 2322.06 g/ha in January 1987, January and April 1988, and March 1989, respectively. Peak loading of TP at QN2 was 2266.64 g/ha in October 1987.

Average losses of TN and TP at QN1 were 0.467 kg/ha and 0.18 kg/ha. At QN2 these values were 1.57 kg/ha and 0.195 kg/ha, respectively.

Through the above sections (3) and (4), the attempts to seek for the important sources and factors, due to the variable losses of N and P in surface runoff, were difficult. But results suggests that conservation tillage practices such as no-till, adopted by some farmers in the watershed, may be effective in reducing N and P losses from the main watershed, QN1.

These results suggest that the subwatershed located above QN2 is contributing significantly to the total nonpoint pollutant losses from the Nomini Creek Watershed.

VI. CONCLUSION

The Nomini Creek Watershed/Water Quality Monitoring Project was initiated in 1985, as part of the Chesapeake Bay Program, to evalute the impact of nonpoint pollution on the watershed. This study on the Nomini Creek Watershed assesses the impact of cropland BMPs on hydrologic conditions and quality of surface water and baseflow during 1987 through 1989. Specific elements of the watershed monitoring system include (wet and dry weather) physical and chemical monitoring of runoff. Several precipitation and runoff monitoring stations were installed throughout the watershed to help investigators better understand the special impact of land-use activities on pollutant losses from the watershed (through the separation of storm runoff and baseflow).

Rainfall-runoff response, defined as the ratio of runoff to rainfall varies for the runoff monitoring site. The results of this study are summarized as follows :

1. The quantitative analyses indicate that rainfall-runoff response varies for the two stations (QN1 and QN2) from storm to storm and depends on storm characteristics and antecedent soil moisture conditions. Rainfall-runoff response was higher at station QN2 than QN1, reflecting the differences in infiltration capacities, and the presence of swamps within the watershed.
2. The volume percentages of storm runoff and baseflow in QN1 watershed averaged 44% and 56%, and at QN2, 25% and 75%, respectively. The differences in runoff characteristics are apparent between the two watersheds. This suggests that the two watersheds differ significantly in their infiltration capacities and aquifer characteristics, and agricultural activities, e.g., landuse agronomic and cultural practices.
3. The results (of the analysis) collected on runoff water quality indicate high levels of both N and P in the stream water. The nitrogen and phosphorus concentration sometimes exceed the minimum levels required for algae growth in the surface water bodies.
4. Most N and P losses from the watershed were in sediment-bound form. Thus, management practices that reduce sediment losses from the watershed should also be effective in reducing nutrient losses to the streams. Since a greater portion on N is in soluble form, as compared to P, these soil conservation practices may be more effective in reducing P losses.
5. Owing to the multiple land uses in each contributing area (monitored at stations QN1 and QN2), attempts to isolate the important sources and factors responsible for variable losses of N in surface runoff are difficult at the present time. However, results suggest that conservation tillage practices such as no-till, adopted by some of the farmers in the watershed, may be effective in reducing N losses from the main watershed, QN1.
6. The losses of P may not cause significant economic loss to farmers. But P concentrations measured at both stations QN1 and QN2 are at a level that could cause water quality deterioration downstream.
7. The concentrations of N and P detected in the baseflow samples collected from the Nomini Creek Watershed are commonly high.

Forthcoming monitoring of the Nomini Creek Watershed would provide a valuable data base for the verification and application of existing water quality simulation models.

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REFERENCES

1. Beasley, D.B., and D.L. Thomas. 1989. Application of water quality models for agricultural and forested watersheds. Southern Cooperative Series Bulletin No. 338. 116 pp. Oct.
2. Bigger, J.W., and R.B. Carey. 1969. Agricultural drainage and eutrophication. pp. 405-445. In : Eutrophication Causes, Consequences and Corrections., Symp. National Academy of Sciences, Washington D.C.
3. Donigian A.S. Jr., and N.H. Crawford. 1976. Modeling nonpoint pollution from the land surface. U.S. Environmental Protection Agency. EPA-600/3-76-083. PP. 1-108.
4. Dunigan, E.P., R.A. Phelan, and C.L. Mondart. 1976. Surface runoff losses of fertilizer elements. J.Environ. Quality. 5(3) : 339-342.
5. Dunigan, E.P., and R.P. Dick. 1980. Nutrient and coliform losses in runoff from fertilized and sewage sludge-treated soil. J. Environ. Quality 9(2) : 243-250.
6. Freeze, R.A. and P.A. Witherspoon. 1966. Theoretical analysis of regional groundwater flow : 1. Analytical and numerical solutions to the mathematical model. Water Resources Research. 2(4) : 64-656.
7. Haan, C.T., H.P. Johnson, and D.L. Brakensiek. 1982. Hydrologic modeling of small watersheds. The American Society of Agricultural Engineers, 533 pp.
8. Jackson, W.A., L.E. Asmussen, E.W. Hauser, and A.W. White. 1973. Nitrate in surface and subsurface flow from a small agricultural watershed. J. Environ. Quality. 2(4) : 480-482.
9. Kenimer, A.L., S. Mostaghimi, T.A. Dillaha, and V.O.Shanholtz. 1989. PLIERS : Pesticide losses in erosion and runoff simulator. Transactions of the ASAE 32(1) : 127-136.
10. Kilmer, V.T., J.W. Gilliam, J.E. Lutz, R.T. Joyce, and C.D. Eklaud. 1974. Nutrient losses from fertilized grassed watersheds in Western North Carolina. J. Environ. Quali-

ty. 3(3) : 214-219.
11. Kissel, D.E., C.W. Richardson, and Earl Bumett. 1976. Losses of nitrogen in surface runoff in the Blackland Prairie of Texas, J. Environ. Quality. 5(3) : 288-293.
12. Klausner, S.D., P.J. Zwerman, and D.F. Ellis. 1974. Surface runoff losses of soluble nitrogen and phosphorus under two systems of soil management. J. Environ. Quality. 3(1) : 42-46.
13. Klausner, S.D., P.J. Zwerman, and D.R. Coote. 1976. Design parameters for the land application of dairy manure. U.S. Environ. Protection Agency EPA-600/2-76-187 : 1-217.
14. Loehr, R.C., D.A. Haith, M.F. Walter, and C. Martin. 1979. Best management practices for agriculture and silviculture. Ann Arbor Science Publishers Inc., Ann Arbor, Michigan.
15. McCuen, R.H. 1989. Hydrologic analysis and design. Prentice-Hall, Inc. pp. 350-468.
16. Mostaghimi, S. 1989. Quality assurance project plan for Nomini Creek Watershed/Water quality monitoring project. Prepared for U.S. EPA Region III. No. QA2-8905, Agricultural Engineering Dept. VPI&SU, Blacksburg, VA, May 1989.
17. Mostaghimi, S., M.M. Deizman, T.A. Dillaha, C.D. Heatwole. 1989b. Impacts of land application of sewage sludge on runoff water quality. Transactions of the ASAE. 32(2) : 491-496, March-April 1989.
18. Mostaghimi, S., P.W. McClellan, U.S. Tim, J.C. Carr, R.K. Byler, T.A. Dillaha, V.O. Shanholtz, and J.R. Pratt. 1989. Watershed/Water quality monitoring for evaluation animal waste BMP effectiveness-Owl Run Watershed. Agricultural Engineering Department, VPI & SU, Pre-BMP evaluation report No. 0-P1-8906. 174 pp.
19. Mostaghimi, S., U.S. Tim, P.W. McClellan, J.C. Carr, R.K. Byler, T.A. Dillaha. V.O. Shanholtz, and J.R. Pratt. 1989. Watershed/Water quality monitoring for evaluating BMP effectiveness-Nomini Creek Watershed. Agricultural Engineering Department, Virginia Polytechnic Institute and State University. Pre-BMP evaluation report No. N-P1-8811. 211 pp.
20. Novotny, V. and G. Chesters. 1981. Handbook of nonpoint pollution, sources, and management. Van Nostrand Reinhold Company. New York. 555 pp.
21. Pettyjohn, W.A., 1987. Protection of public water supplies from ground-water contamination, Pollution Technology Review No. 141. Noyes Date Corporation. pp. 82-101.
22. Römkens, M.J. M., D.W. Nelson, and J.V. Mannering. 1973. Nitrogen and phosphorus composition of surface runoff as affected by tillage method. J. Environ. Quality 2(2) : 292-295.
23. Runge, C. 1976. Land management institutional design for water quality objectives. In : Proc. of the best management of practices for nonpoint source pollution seminar. EPA-905/76-005, U.S. Environmental Protection Agency, Chicago, Illinois.
24. Schreiber, J.D., P.D. Duffy, and D.C. McClurkin. 1976. Dissolved nutrient losses in storm runoff from five southern pine watershed. J. Environ. Quality. 5(2) : 201-205.
25. Schuman, G.E., R.E. Burwell, R.F. Piest, and R.G. Spomer. 1973. Nitrogen losses in surface runoff from agricultural watersheds on Missouri Valley Loess. J. Environ. Quality, 2(2) : 299-302.
26. Singh, K.P. 1976, Unit hydrographs-A comparative study. American Water Resources Association. Water Resou. Bull 12(2) : 381-392.
27. Spooner, J., R.P. Mass, S.A. Dressing, M.D. Smolen, and F.J. Humenik, 1985. Appropriate designs for documenting water quality improvements from agricultural NPS control programs. In : Prospective on nonpoint source pollution. EPA 440/5-85-001. pp. 30-34.
28. Taylor, A.W., W.M. Edwards, and E.C. Simpson. 1971. Nutrients in streams draining woodland and farmland near Coshocton, Ohio. Water Resour. Res. 7(1) : 81-89.
29. Thomas, G.W., and J.D. Crutchfield, 1974. Nitrate-nitrogen and phosphorus contents of streams draining small agricultural watersheds in Kentucky. J. Environ. Quality. 3(1) : 46-49.
30. Timmons, D.R., R.E. Burwell, and R.F. Holt. 1973. Nitrogen and phosphorus losses in surface runoff from agricultural land as influenced by placement of broadcast fertilizer. Water Resour. Res. 9(3) : 658-667.