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STORM-WATER AND BASEFLOW SAMPLING AND ANALYSIS IN THE NANTICOKE RIVER WATERSHED: PRELIMINARY REPORT OF FINDINGS 2002-2004

By

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	*By*	*To obtain*
inch (in.)	25.4	millimeter (mm)
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
pounds	0.454	kilograms
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
pounds per day (lb/d)	0.454	kilograms per day (kg/d)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8ˇ°C)+32
Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
°C=(°F-32)/1.8

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

micromolar (µM) = one one millionth of a mole per liter

STORM-WATER AND BASEFLOW SAMPLING AND ANALYSIS IN THE NANTICOKE RIVER WATERSHED: PRELIMINARY REPORT OF FINDINGS 2002-2004*

***Note: Sections of this report that describe analytical methods are excerpted from Ullman, W. J., A. S. Andres, J. R. Skudlark, and K. B. Savidge, 2002, Storm-Water and Base-Flow sampling and Analysis in the Delaware Inland Bays Preliminary Report of findings 1998-2000: Delaware Geological Survey Open file Report No 44.**

ABSTRACT

This report provides initial research results of a storm-water and baseflow sampling and analysis project conducted by the University of Delaware, College of Marine and Earth Studies and the Delaware Geological Survey. Baseflow samples were collected from four tributary watersheds of the Nanticoke River and one station on the Nanticoke River on 18 occasions from March 2003 to June 2004. Water samples were filtered in the field to separate dissolved nutrients for subsequent analysis, and separate samples were collected and returned to the laboratory for particulate nutrient determinations. On each sampling date, temperature, conductivity, pH, and dissolved oxygen concentrations were determined at each sampling station. The U.S. Geological Survey made stream discharge measurements at each of these sites under a joint-funded agreement with the Delaware Department of Natural Resources and Environmental Control and the Delaware Geological Survey. Together, the nutrient and discharge data were used to determine the total nutrient loads at five stations and unit loads (normalized to watershed area) at two of those stations on a quarterly and annual basis. Problems with watershed delineation and low quality discharge data limit these calculations for some watersheds. At the same five stations, storm water was collected during six storms from March 2003 to June 2004. Storm-water loadings of nutrients in each watershed were calculated from the concentrations of nutrients in water samples collected at fixed time intervals from the beginning of the storm-water discharge period until recession to baseflow. Measured storm loads were used as the basis for estimating loads from unsampled storms. These data provide the Delaware Department of Natural Resources and Environmental Control with a more complete picture of the seasonal dependence of nutrient loading to streams in the Nanticoke River watershed and to Chesapeake Bay receiving waters. These may also be used to establish total maximum daily load goals.

INTRODUCTION

The impact of agricultural, domestic, municipal, and industrial practices on the environmental status of the Nanticoke River watershed (Sussex County, Delaware) has been well documented over the last ten years by the U.S. Environmental Protection Agency (EPA) Chesapeake Bay Program, the Delaware Department of Natural Resources and Environmental Control (DNREC), the Delaware Geological Survey (DGS), the U.S. Geological Survey (USGS), the University of Delaware, and other agencies (Ritter and Scarborough, 1997; EPA, 1998, 2002; DNREC, 2000; Tiner et al., 2001; Denver et al., 2004). The documentation of the effects of these practices and the impact of regulation on the ecological status of the Nanticoke River is an important consideration for the management of this environmentally, recreationally, and economically important resource. Until now, however, there has not been a sufficient database from which to determine the impact of particular land uses, land cover, and land-use practices on nutrient and carbon fluxes, and the seasonal variations and the impact of storm events on fluxes from the portions of the watershed within Delaware. Determining the magnitudes and mechanisms of transport of the nutrient elements, nitrogen and phosphorus, and organic carbon (a contribution to estuarine oxygen demand) through the watershed to estuarine receiving waters has become a priority for federal, state, and local government agencies with management responsibilities in this watershed.

Purpose and Scope

Building on work completed in the Inland Bays watershed (Ullman et al., 2002), DNREC supported a cooperative program with the University of Delaware, College of Marine and Earth Studies (CMES) and DGS to collect and analyze water samples from selected discharge points in the Nanticoke River watershed under baseflow and stormflow conditions. The discharges of water, nutrients, and organic carbon were analyzed from several contrasting subwatersheds (Fig. 1, Table 1) from March 2003 through June 2004. The program included four tasks:

1. Acquisition of water-quality samples for at least six rainfall events from each of five gaging stations selected by DNREC;
2. Acquisition of baseflow discharge samples on roughly a monthly basis from each of the sampling sites;
3. Preparation and analysis of the samples using documented methods of analysis; and
4. Documentation of the quality control, quality assurance, and analytical results obtained under 1, 2, and 3, above.

This report documents the preliminary results of the collaborative program. The data on which the report is based are separately reported in a Microsoft Access database (Andres et al., 2005a). This database is equipped with queries that permit easy uploading and downloading of analytical data, quality control of these data, and display of the data in various formats. In the event of corrections and additions to the database, updates will be available on the Delaware Geological Survey Web site at http://www.udel.edu/dgs/.

Table 1. Nanticoke River watershed sampling sites.

Site	Reason for Selection	USGS Identifier
Trap Pond Outlet	State park; impoundment with mixed land use	DE01487500
Mifflin Ditch at Rt. 113 near Georgetown	Forest and wetland	DE01487060
Nanticoke River at Bridgeville	Mixed land use, large discharge	DE01487000
Herring Run Tributary near Seaford	Commercial development	DE01487195
Dukes and Jobs Ditch	Ditched crop land, poultry production	DE01487698

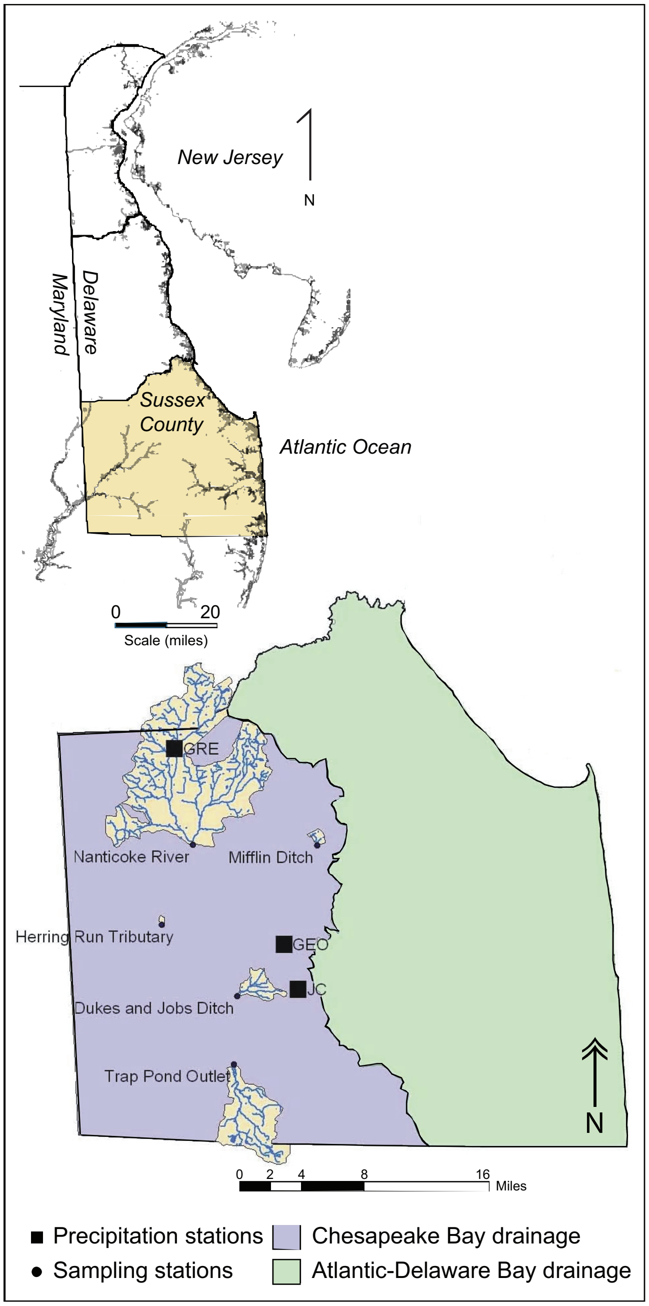

Figure 1. Location of sampling stations, watersheds, and precipitation stations in the Nanticoke River watershed. GRE = Greenwood; GEO = Georgetown; JC = Jones Crossroads.

Acknowledgements

This work was funded by the DNREC, DGS, and CMES. We thank Mark P. Neimeister and Bailey L. Dugan for their assistance with data management and data analysis. We also thank Anthony Tallman and his colleagues at the U.S. Geological Survey for their perseverance in updating the rating curve for Mifflin Ditch.

METHODS

Watershed Delineations

Watershed delineations for areas upstream of the five sampling stations were prepared manually by DGS personnel and were based on the 1992 edition 1:24,000-scale USGS topographic maps and associated digital line graph (DLG) products, and supplemented by field observations, aerial photograph analyses, and visual comparison to watershed boundaries distributed by DNREC. Boundaries were electronically captured as shape files by heads-up digitizing in ArcMap (ESRI, 2003). Additional updated digital hydrography data were obtained from DNREC (John Inkster, personal communication) for the Mifflin Ditch watershed. In general, differences between watershed delineations between this study and DNREC were minor.

Automated watershed delineations were attempted using the ArcMap Hydrology Toolbox and 30-m digital elevation models (University of Delaware Spatial Analysis Lab, http://www.udel.edu/FREC/spatlab/dems/co_dems.html); however, the process was unsuccessful because of the low topographic relief in this portion of the Nanticoke River watershed. In general, low topographic relief and ditching, which are present throughout the study area, are problematic for accurately delineating watersheds. Ditching creates unquantifiable errors because it connects and allows flow between adjacent watersheds defined by topography. In addition, field surveys conducted in the Mifflin Ditch watershed detected many small ditches that were not present on map and DLG products.

Land-use area and percentage calculations for the sampled watersheds were computed from the 1-meter resolution land cover dataset covering Sussex County obtained from Mackenzie and McCullough (1999) and the Delaware Office of State Planning Coordination (1999). This dataset was made from 1997 aerial imagery. ArcMap (ESRI, 2003) was used to cull the data with the intersect feature of the Geoprocessing wizard.

Sampling and Analytical Methods

Baseflow water samples were collected from each sampling station at approximately monthly intervals from March 2003 to June 2004 (Table 2) when a minimum of three days passed with no measurable precipitation recorded at the Research and Education Center, Georgetown, Delaware (Research and Education Center, 2005). At each station, a clean one-liter bottle was filled by dipping it below the surface layer of the tributary or by using a peristaltic pump. In each case, the bottle was rinsed at least three times with stream water prior to sample collection. An aliquot sample was filtered immediately after collection through Whatman GF/F glass-fiber filters (0.7 micron nominal pore size) for dissolved nutrient analyses. This sample, together with the remaining unfiltered sample, was stored on ice in the dark until returned to the laboratory. Water temperature, conductivity, pH, and dissolved oxygen were determined at each station at the time the sample was collected.

Within five hours after a sample was collected, a 10-ml aliquot of the filtered dissolved-nutrient sample was ampulated for subsequent determination of dissolved organic carbon (DOC). A second 15-ml aliquot was separated for dissolved silicate (Si) analysis and refrigerated until analyzed. The remaining filtered sample and the ampules were then frozen until ready for the determination of dissolved constituents. On return to the laboratory, particles from the unfiltered sample were collected onto either precombusted (500 °C for 2 hours) GF/F filters for the determination of particulate organic carbon and nitrogen (POC and PON), or fresh GF/F filters for particulate phosphorus (PP) and chlorophyll *a*. Total suspended solids (TSS) were determined by collection on tared 47-mm diameter, 0.4μm pore-size Nuclepore® filter membranes.

The samples for dissolved-nutrient and DOC analysis were frozen for up to one year until analyzed. The Si samples were refrigerated for up to three months until analyzed. If the chlorophyll *a* samples could be analyzed within 24 hrs, the samples were immediately treated with 90% acetone; if not, the samples were frozen for up to a month and acetone was added 24 hours before analysis. TSS samples were weighed, dried under a heat lamp, and reweighed within a few days of collection. Samples for PON, POC, and PP were dried and stored for up to one year until analyzed. These storage protocols were designed to minimize the degradation of samples prior to analysis. No storage effects were noted in this study.

Storm-water samples were collected using Isco 6700 automatic samplers on six occasions from April 2003 to June 2004 (Table 3). Storm-water sampling was automatically enabled by an increase in tributary stage height of at least 0.006 m subsequent to the manual arming of the sampler. Samples were collected immediately upon enabling and at variable intervals of 1 to 12 hrs for up to 48 hrs (typically 12 samples were collected per event). During warm weather, ice packs were placed in the Isco sample compartment to retard biogeochemical reactions that might alter the water chemistry. Samples were collected in clean one-liter bottles and stored on ice in the dark until returned to the laboratory for filtering and analysis. In the laboratory, conductivity and pH were determined and aliquot samples were taken and filtered, as described above, for dissolved and particulate nutrient and carbon analysis and for the determination of TSS and chlorophyll *a*. We attempted to sample all stations during the same rain event. However, rainfall was, during some events, insufficient to trigger the Isco samplers at some sites. Under these conditions, samples were collected on a later date.

In the field, conductivity was determined using a Cole-Parmer Model 1481-40 conductivity meter calibrated using KCl standards purchased from Oakton Instruments. The pH of the sample was determined potentiometrically using an Orion 210A pH meter calibrated using commercial NBS-traceable standards. Dissolved oxygen was determined potentiometrically using a Yellow Springs Instrument Model YSI58 dissolved oxygen meter calibrated in water-saturated air. Temperature measurements were taken using the thermistor on the dissolved oxygen meter. The water-quality parameters measured are summarized in Table 4.

Samples for particulate organic carbon (POC) and nitrogen (PON), together with the precombusted 13-mm GF/F (glass fiber) filter on which they were collected, were encapsulated in clean tin cups, dried and stored in a desiccator until combusted, and analyzed either on a Carlo Erba Model EA1108 CHNS Elemental Analyzer (early in the research project period) or on a similar Costech Model ECS4010 Elemental Combustion Analyzer (late in the project period). Between 25 and 75 ml of sample were filtered for the PON and POC analyses depending on the turbidity of the sample. The instruments were calibrated using weighed samples of ethylenediaminetetraacetic acid (EDTA--$C_{10}H_{16}O_8N_2 \cdot 2H_2O$) and phenylalanine ($C_9H_{11}O_2N$).

Table 2. Dates of baseflow sample collection.

Spring 2003	Summer 2003	Fall 2003	Winter 2004	Spring 2004
Mar. 11	June 27	Oct. 8	Dec. 23	Mar. 30
Apr. 3	July 22	Nov. 18	Feb.13	May 10 & 14
May 1	Aug. 22		Mar. 1	June 4
June 12	Sept. 12			June 10

Table 3. Dates and designations of storm-water sampling.

Site	SA03	SB03	SC03	SD03	SE04	SF04
Trap Pond Outlet	April 25-27, 2003	July 9-11, 2003	Sept. 12-14, 2003	Oct. 26-29, 2003	Mar. 30-Apr. 2, 2004	June 5-6, 2004
Mifflin Ditch	May 21-23, 2003	July 9-11, 2003	Sept. 12-14, 2003	Oct. 26-29, 2003	Mar. 30-Apr. 2, 2004	June 5-6, 2004
Nanticoke River	April 25-27, 2003	July 9-11, 2003	Sept. 23-25, 2003	Oct. 26-29, 2003	Mar. 30-Apr. 2, 2004	June 5-6, 2004
Herring Run Tributary	April 25-27, 2003	July 9-11, 2003	Sept. 12-14, 2003	Nov. 19-21, 2003	Apr. 1 - Apr. 2, 2004	June 5-6, 2004
Dukes and Jobs Ditch	April 25-27, 2003	July 9-11, 2003	Sept. 12-14, 2003	Nov. 19-21, 2003	Mar. 30-Apr. 2, 2004	June 5-6, 2004

Table 4. Water-quality measurements made at Nanticoke River watershed sites.

Field Measurements	Lab Measurements: Particulate	Lab Measurements: Dissolved
Conductivity	Organic Carbon	Ammonium
pH	Organic Nitrogen	Nitrate+Nitrite
Temperature*	Phosphorus	Total Dissolved Nitrogen
Dissolved Oxygen*	Total Suspended Solids	Phosphate
	Chlorophyll *a*	Total Dissolved Phosphorus
		Silicate
		Dissolved Organic Carbon

Temperature and dissolved oxygen were not determined on stormwater samples.

Between 25 and 100 ml of sample, depending on turbidity, were filtered for particulate phosphorus (PP) analysis. Samples, together with the clean GF/F filter on which they were collected, were stored in the dark and dried in glass scintillation vials until combusted (450 - 500 °C for 2 hrs), dissolved, and subsequently analyzed as dissolved phosphate. Prior to drying, the sample and filter were soaked in 2 ml of 0.017 M $MgSO_4$ to prevent the formation of insoluble phosphate compounds on combustion. After cooling, 5 ml of 0.2 M HCl were added to each vial, and the samples were heated to 80 °C for 30 minutes to dissolve the combustion residue. The concentration of phosphate was determined colorimetrically in the supranatant using the phosphomolybdenum blue method (Solórzano and Sharp, 1980a).

Up to 200 ml of water sample were filtered through membrane filters, depending on turbidity, for the determination of total suspended solids (TSS). The sample retained on the filter was then re-dried for 2 hrs under a heat lamp and weighed.

Up to 200 ml of sample, depending on turbidity, were filtered onto a 25-mm GF/F filter for the determination of chlorophyll *a*. The filter and sample were placed into a glass scintillation vial. The acetone-extracted chlorophyll was determined fluorometrically on a Turner AU10 Fluorometer. Commercially purchased chlorophyll *a* was standardized using the spectrophotometric method of Parsons et al. (1984) and subsequently used to calibrate the fluorometric determinations.

Dissolved ammonium (NH_4^+, abbreviated NH_4 in this report), nitrate+nitrite ($NO_3^- + NO_2^-$, abbreviated NO_3), and phosphate (ΣPO_4^{3-}, abbreviated PO_4), were determined by automated colorimetry on filtered samples using an O/I Analytical Flow Solution IV Analyzer. NH_4 was determined by the phenol hypochlorite method (Glibert and Loder, 1977; Grasshoff and Johansen, 1972). NO_3 concentration was determined by the sulphanilamide/N(1-napthyl) ethylene diamine method after cadmium reduction of NO_3 to NO_2 (Glibert and Loder, 1977). PO_4 was determined by the phospho-molybdenum blue method (Strickland and Parsons, 1972). Total dissolved nitrogen (TDN) and phosphorus (TDP) were determined as NO_3 and PO_4 after oxidation in an autoclave by multiply-reprecipitated potassium persulfate ($K_2S_2O_8$) (Glibert and Loder, 1977; D'Elia et al., 1977; Solórzano and Sharp, 1980b).

Dissolved organic nitrogen and phosphorus (DON and DOP) were determined as the difference between the dissolved total concentrations (TDN and TDP) and inorganic concentrations (DIN = NO_3 + NH_4 and DIP = PO_4).

Dissolved organic carbon (DOC) was determined on the ampulated samples after acidification and bubbling with helium to remove inorganic carbon. Samples were then catalytically combusted in a Shimadzu TOC 5000 and detected by non-dispersive infrared analysis. The instrument was calibrated using aqueous solutions of potassium hydrogen phthalate ($KHC_8H_4O_4$).

All of these methods are routinely used in the CMES laboratories. The estimated precision of each analysis is given in Table 5. Because of the uncertainties in the component analyses, the precision of the calculated values of DON and DOP is ± 2.2 - 11 micromolar (µM), and ± 0.03 - 0.07 µM, respectively. Total nitrogen (TN = TDN + PON), phosphorus (TP = TDP + PP), and organic carbon (TOC = DOC + POC) have uncertainties of ± 2 - 10 µM, ± 0.03 - 0.05 µM, and ± 15 - 50 µM, respectively.

Quality control of the water-quality data was achieved by comparing measurements to prepared samples and blanks, by replicated analysis of selected samples, by participation in interlaboratory comparisons (Sharp et al., 2004; Chesapeake Bay Program, 2001-2004), and by detailed examination of the data after the analyses were completed. In the case of TDN and TDP, analyses were repeated when the difference between these values and the sum of their separately determined inorganic components was significantly less than zero. Other analytical outliers were identified by examining trends for each parameter and examining correlations between related parameters at each location. Direct electronic transmission of data from the analytical source to the database was used whenever possible to minimize the opportunity for transmission and data entry errors.

All reported calculations are based on these quality-assured chemical data. Any errors or potential errors identified by users of the data from this project should be reported to the authors for verification and correction.

Table 5. Typical precision achieved for each analytical procedure used in this study.

Field Measurements		Particulate Constituents		Dissolved Constituents	
Conductivity	± 20 µS	Organic C (POC)	± 3-6 µM	Ammonium (NH_4)	± 0.2-1 µM
pH	± 0.2	Organic N (PON)	± 0.5-1 µM	Nitrate+Nitrite (NO_3)	± 1-5 µM
Temperature	± 0.3 °C	Suspended Solids	± 0.2 mg/L	Total N (TDN)	± 0.2 mg/L
Dissolved Oxygen	± 0.05 mg/L	P (PP)	± 0.02 µM	Phosphate (DIP=PO_4)	± 0.02 µM
		Chlorophyll *a*	± 0.2-5 µg/L	Total P (TDP)	± 0.2-5 µg/L
				Organic Carbon (DOC)	±15-50 µM

Hydrographic Methods

Instrumentation and systems used to measure, record, and compute stream stage height, discharge, and precipitation were operated, maintained, and subjected to QA/QC procedures by the USGS Water Resources Division. Continuous discharge records were obtained at all of the sampling stations (Table 1). These stations electronically recorded the stage height at 15-minute intervals. USGS staff developed and maintained stage height-discharge rating curves and provided access to their database of computed instantaneous and mean daily discharge values. Daily mean and instantaneous (15-minute reading interval) discharge data were retrieved from the USGS-ADAPS database (USGS, 2004) in November 2004 and in January 2007. The 15-minute stage height-discharge data were used for the determination of storm-water discharge and loadings. Mean daily discharges were used to determine quarterly and annual loadings.

Baseflow separations were completed manually using methods described by Gray (1970) and Maidment (1993). Prior hydrograph separation work by Johnston (1976) provided practical guidance for the current study. Baseflow separations were created using the following procedure:

1. A semi-logarithmic plot of the hydrograph and a precipitation time series were constructed using plotting software.
2. A series of characteristic recession curves for each station was generated. The baseflow hydrograph (recession curve) was digitized on screen to be equal to streamflow during baseflow periods. Baseflow periods were those when a minimum of three days passed with no measurable precipitation.
3. The baseflow hydrograph was visually estimated for periods during and following precipitation. First, an estimated baseflow recession curve was extended forward under the rising limb of the storm hydrograph to the point of peak flow. Next, an estimated baseflow curve was extended backward from the subsequent baseflow recession toward the point of peak flow.
4. The baseflow curve under the storm hydrograph was estimated by considering the shape of the storm hydrograph, the preceding and following recession curves, and the timing of storm precipitation.
5. The difference between total flow and baseflow was considered to be a combination of overland and near-stream shallow subsurface flow (e.g. interflow). Separation of overland flow and interflow was not attempted.

These calculated flow components allow computation of nutrient fluxes and volumes of baseflow and stormflow during storm periods. These values could be used to identify watersheds with similar hydrologic characteristics. They are used with chemistry data for computations of chemical mass loadings and for determining the relationships between streamflow and concentration, which may be useful for estimating loading from unsampled storms.

Loading Computations

Daily mean streamflows were classified as either “all baseflow” or “all stormflow” for computing monthly and annual loadings. Flow for a particular day was classified as “all baseflow” when stormflow from the hydrograph separation was less than 5 percent of total flow. Flow for a particular day was classified as “all stormflow” when stormflow from the hydrograph separation was greater than 5 percent of total flow. This is an arbitrary threshold. The result of using smaller or larger thresholds is that a smaller or larger fraction of the total discharge and computed loads is assigned to stormflow. Total loads are minimally affected by this arbitrary choice.

Daily mass loadings of dissolved and particulate constituents were computed from the mean daily discharges and the estimated concentrations of constituents. The estimated daily mass loadings were summed to give monthly mass loadings for each of the five watersheds. Quarterly and annual loadings were then calculated from these results.

Daily concentrations of chemical constituents during baseflow conditions were estimated by linear interpolation between the previous and subsequent baseflow samples collected and analyzed at each site. Missing data, if any, were estimated using the same technique. For the period March 1-22, 2003, prior to the initiation of baseflow sampling, the concentrations of N, P, and organic carbon (DOC and POC) were assumed to be those of the initial baseflow sample collected on March 23, 2003. For the period June 11-30, 2004, the concentrations of N, P, and organic carbon (DOC and POC) were assumed those of the final baseflow sample collected on June 10, 2004.

Baseflow loadings were calculated from discharge data supplied by the USGS. In some cases, incomplete discharge data sets and incomplete quality control hampered the determination of baseflow and storm-water loadings. Estimated flows were computed using stage-height records collected by the Isco samplers and the appropriate rating tables provided by the USGS.

Stormflow loadings were computed as the product of measured constituent concentration and time-integrated discharge for the period centered on the time that an individual storm sample was collected. For events when sampling did not cover the entire period of the storm and storm-water recession, the calculated loads cover only the sampled intervals. Volume-weighted average concentrations of chemical constituents were calculated at each station as the total mass of chemical constituent for the storm divided by the total flow volume for the storm. These volume-weighted concentrations were assumed to represent seasonal concentrations during all unsampled storms within the corresponding season and were used in loading computations for all unsampled storms.

Because of the small size of the stream, the poor condition of the stream channel, and frequent changes to the channel configuration, operation of the stage-height recorder at the Herring Run Tributary was problematic; therefore, the reliability of the discharge data was assigned a poor rating (Anthony Tallman, personal communication). After March 2004, stage-height data collected by the USGS and the Isco

Table 6. Watershed areas and land use/land cover (LULC) analysis as determined by delineation. LULC fractions are reported as percentages of total watershed area.

LULC Class	Trap Pond Outlet	Mifflin Ditch	Nanticoke River	Herring Run Tributary	Dukes and Jobs Ditch	All Watersheds
Built-up (100)	7.3	3.3	7.7	60.5	6.3	8.2
Agriculture (200)	45.9	2.6	56.6	29.3	61.9	55.3
Scrub, barren (300)	4.8	3.2	4.4	0.0	3.0	4.3
Forest (400)	28.5	22.8	13.4	6.2	21.7	15.7
Wetland (600)	12.9	68	17.3	3.4	4.8	15.9
Other (500+700)	0.6	0.1	0.6	0.7	2.2	0.66
Area (km^2)	43.2	3.89	195	0.34	8.37	250

Table 7. Annualized water budgets for monitored watersheds for the period April 1, 2003 to March 31, 2004.

Sampling Station	Mean Flow (m^3/s)	Unit Discharge ($m = m^3/m^2$)	Baseflow (%)	Stormflow (%)
Trap Pond Outlet	0.829	0.60	61	39
Mifflin Ditch	0.0099	0.39	58	42
Nanticoke River	4.65	0.75	85	15
Herring Run Tributary	0.015	1.38	7	93
Dukes and Jobs Ditch	0.293	1.10	61	39

Note: Total precipitation during this period was 1.41 m (Georgetown), 1.32 m (Greenwood), and 1.27 m (Delaware Solid Waste Authority, Jones Crossroads). See Figure 1 for locations.

sampler were below the level for which the USGS rating curve was appropriate; however, visual examination of the site indicated that a small amount of discharge was occurring. USGS personnel indicated that it may be possible to estimate daily mean flows at this site from discharge records of nearby stations. Because such calculations introduce additional and uncontrolled sources of uncertainty to the discharge and the load calculations, they were not used in this report.

Due to incomplete calibration of rating curves at high flows, the quality of the reported discharge during and after storm events at Dukes and Jobs Ditch and Mifflin Ditch also was assigned a poor rating (Anthony Tallman, personal communication). Additional work to improve the accuracy of the rating curve at high flows for Mifflin Ditch was completed by the USGS during 2006 and the discharge values were subsequently updated using the new rating curve (Anthony Tallman, written communication). The reported loads for Mifflin Ditch in this document supersede those reported in previous reports (Andres et al., 2005b).

RESULTS

Watershed Characterization and Water Budgets

The area of each watershed discharging at the five sampling locations is shown in Table 6. The watersheds have a range of distributions of land uses (LU) and land covers (LC) that are representative of the range of land uses found elsewhere in the Sussex County (Delaware Office of State Planning Coordination, 1999; Mackenzie and McCullough, 1999).

Total precipitation for the period April 1, 2003, to March 31, 2004 was 1.41m (~55 inches) at Georgetown (Research and Education Center, 2005). This was an above normal period of precipitation (125 percent of normal). There were 143 days with measurable precipitation during this period, including 37 events that lasted more than one day. Total precipitation during the same period was 1.32 m (~52 inches) at Greenwood (Daniel and Connie Swartzentruber, written communication; http://www.udel.edu/leathers) and 1.27 m (50 inches) at Jones Crossroads (Dan Fluman, personal communication).

A standard way to evaluate watershed hydrology is to compute area-normalized water budgets. In evaluating the streamflow portion of the water budget, the unit discharge (discharge per unit area) of Herring Run tributary is nearly the same (about 98 percent) as the amount of precipitation that fell on the watershed at Georgetown. Likewise, the unit discharge for Dukes and Jobs Ditch comprises a larger than normal proportion (78 percent) of the precipitation amount during the same period (Table 7). Johnston (1976) reported total stream discharge to precipitation ratios in the range of 60 to 70 percent. While it is known that the reported discharges are inaccurate, particularly during periods of highest discharge, it is also possible that the delineation of the watersheds, based on surface topography, underestimates the areas of the true watersheds that discharge at these gaging sites (Kasper, 2006). It is possible that the subsurface watersheds are substantially larger than the topographically delineated surface watersheds. The excessive unit discharge also could be due to recent changes in ditch configuration that cause the surface watershed to be larger than indicated by even the most recent topographic maps. Accurate evaluation of these possibilities would require additional measurements of streamflow during high-flow periods, installation of monitoring wells, a multi-year water-level measurement project, and detailed field surveys of topography and artificial drainage structures that are beyond the scope of this project and report. The result of not having reliable watershed delineations is that area-normalized loading rates of chemical constituents cannot be accurately computed for some of the sampled watersheds. Further analysis of unit runoff (Fig. 2) by month shows that runoff is significantly in excess of precipitation in the Herring Run Tributary watershed during some months but not others.

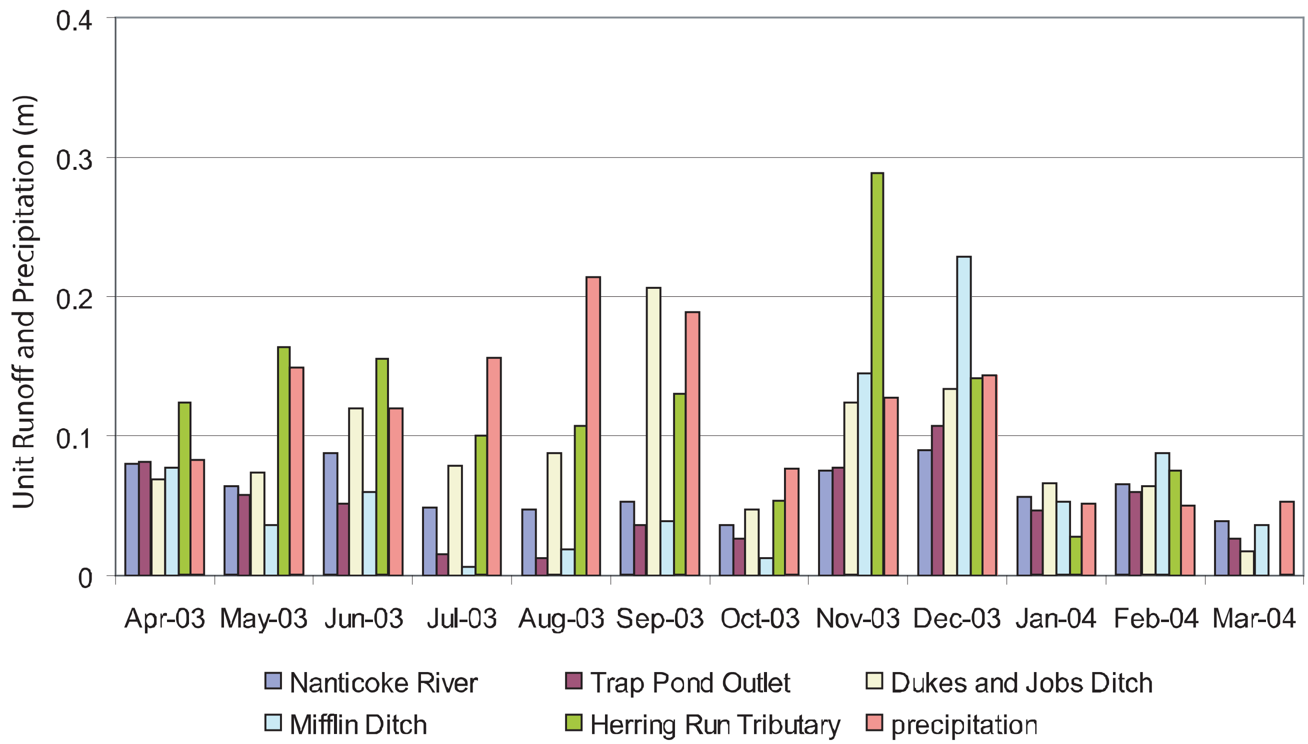

Figure 2. Monthly unit runoff and precipitation (measured at Georgetown, REC 2005).

The relative proportions of baseflow and stormflow (Table 7) for the Nanticoke River, Trap Pond Outlet, Mifflin Ditch, and Dukes and Jobs Ditch are comparable to proportions reported by Johnston (1976) and Ullman et al. (2002), while baseflow proportions for Herring Run Tributary are substantially smaller. The slightly higher proportion of stormflow in the water budget for the Mifflin Ditch watershed is likely due to a combination of ditching and a very shallow water table (Martin and Andres, 2005). The problems with discharge measurements at the Herring Run Tributary mentioned previously preclude any detailed analysis of the water and nutrient budgets for that watershed.

Baseflow Discharge and Water Quality

The nutrient chemistry of the waters that discharge at each gaging station reflects the origin of the water, the addition or removal of nutrients at the land surface due to natural and cultural processes, and the transport of the water and its associated nutrient load through ground and surface pathways to the station. In-stream and in-pond processes may also affect nutrient concentrations, speciation, and loads. As the chemistry at each gaging station reflects the different hydrological and land use characteristics of its watershed, there are significant differences in the seasonal patterns of nutrient concentrations and loadings at each site.

The results of correlation analysis (linear, exponential, and logarithmic) between concentrations of different chemical species and between chemical species and discharge also indicate interactions between hydrological transport and biogeochemical characteristics of the watersheds. Some of the correlations are noted where the correlation coefficients (r) are greater than 0.6, a value that indicates a potentially significant relationship between variables.

Trap Pond near Laurel, Del. (USGS DE01487500)

Trap Pond drains an agricultural and forested watershed through a substantial man-made impoundment (Table 6). Baseflow discharge peaks during the winter and early spring; discharge is moderated by high rates of evapotranspiration during the summer. Substantially more rain fell during the 2003 calendar year than in an average year (Research and Education Center, 2005). In contrast, 2004 was a dry year. The patterns of nutrient concentrations and loading (Fig. 3) largely reflect biogeochemical processes that take place in the 107-acre pond and its associated wetland and forested wetland areas.

Peaks in total dissolved nitrogen (TDN) concentrations (150 – 200 μM N) occur in the winter months when aquatic plant activity and associated nitrogen uptake in the impoundment is at its minimum and flow is at a maximum. These high TDN levels reflect the agricultural nature of the watershed and the low rates of nitrogen attenuation in the impoundment during colder months and shorter days. During the mid- to late-summer, when aquatic and wetland plant production and associated attenuation by the impoundment are at their maxima, dissolved inorganic nitrogen (DIN = nitrate + nitrite + ammonium) is largely absent and dissolved nitrogen export downstream is at its minimum. Dissolved organic nitrogen (DON) is the dominant dissolved form of nitrogen during the summer months. The nitrogen load during the summer is dominated by particulate organic nitrogen (PON), presumably produced by organisms in the pond.

Particulate phosphorus (PP) is the dominant form of phosphorus in baseflow during much of the sampling period. With the exception of a single sample collected on June 12, 2003, that reflects the impact of a particularly large storm 5

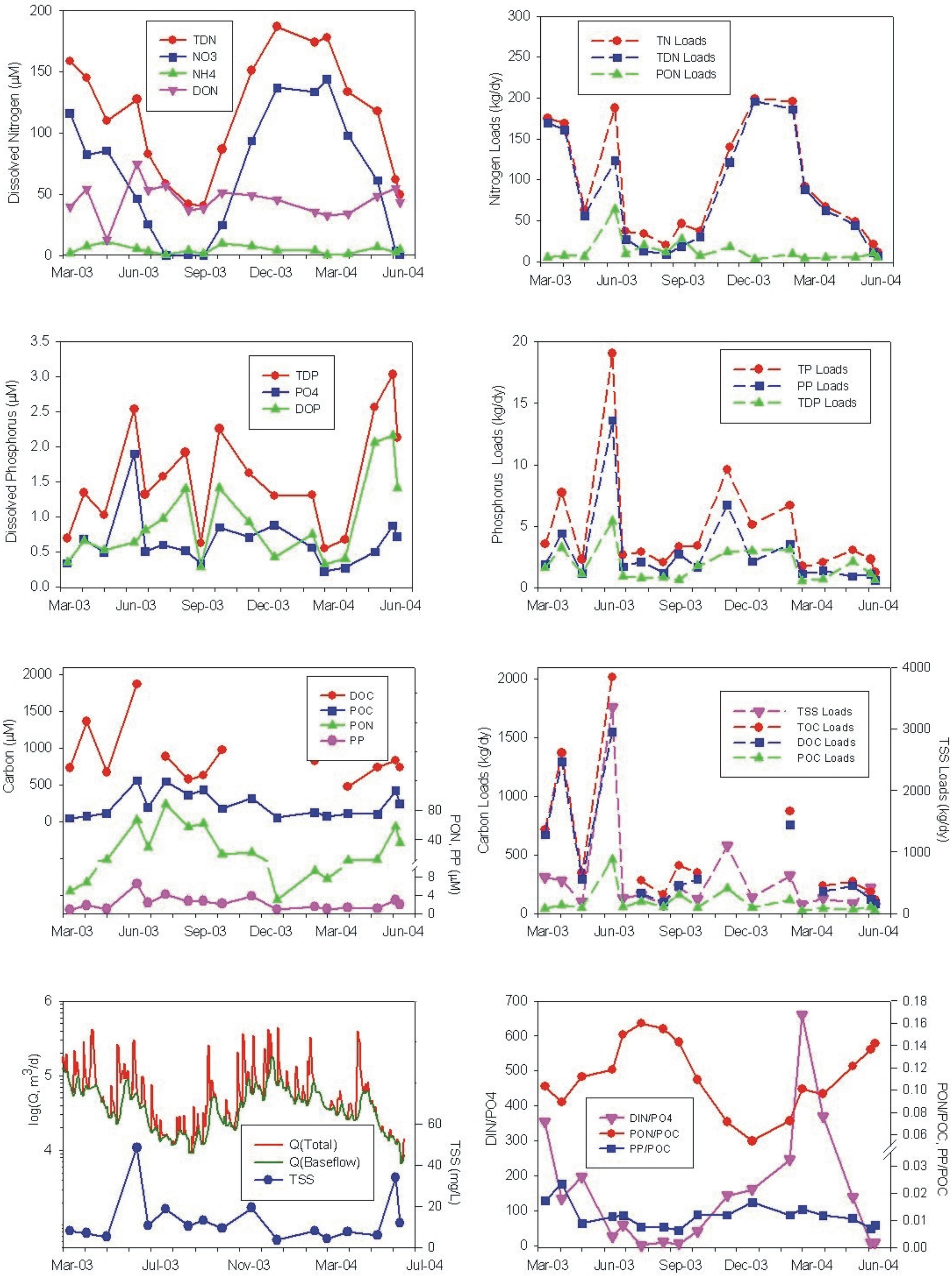

Figure 3. Nutrient (mM) and suspended solids (mg/L), instantaneous loads at baseflow (kg/d), and discharge (m^3/d) determined at Trap Pond near Laurel, Del.

days earlier (6.5 cm on June 7, 2003; Research and Education Center, 2005), phosphate (PO_4) concentrations do not exceed 1 μM. Dissolved organic P (DOP) exceeds the PO_4 concentration a number of times during the year. Compared to TDN, however, TDP concentrations are far less variable.

The above observations and the DIN/PO_4 ratios that follow the pattern set by DIN concentrations suggest that the primary productivity of Trap Pond is limited primarily by
Education Center, 2005), phosphate (PO_4) concentrations do not exceed 1 μM. Dissolved organic P (DOP) exceeds the PO_4 concentration a number of times during the year. Compared to TDN, however, TDP concentrations are far less variable.

The above observations and the DIN/PO_4 ratios that follow the pattern set by DIN concentrations suggest that the primary productivity of Trap Pond is limited primarily by
DIN availability during the mid- to late-summer months. During the late-spring to late-summer period, the particulate organic carbon and nitrogen (POC and PON) composition of the particulate matter discharging from the pond is consistent with a primarily live planktonic origin (PON/POC ≈ 16/106 ≈ 0.15; Redfield et al., 1963); during the rest of the year, particles are apparently of terrestrial or dead-aquatic origin (PON/POC « 0.15).

The primary productivity in Trap Pond serves to alter the speciation and moderate the loads of nitrogen and possibly phosphorus from this watershed to estuarine receiving waters. Settling in the pond may attenuate allochthonous and autochthonous particulate forms of nitrogen, phosphorus, and carbon.

Mifflin Ditch near Georgetown, Del. (USGS DE01487060)

Mifflin Ditch drains a primarily wetland and forested watershed (Table 6) and the water chemistry determined at this site (Fig. 4) reflects the nature of the land use and the relative lack of agricultural and domestic impacts in this watershed. The water is highly colored, with high levels of dissolved organic carbon (DOC) compared to the other watersheds sampled, reflecting the discharge from wetland soils. TDN concentrations rarely exceed 60 μM N and are found primarily in the form of DON. DIN concentrations rarely exceed 10 μM N and at many times of the year NH_4 exceeds NO_3 concentrations. PP is the dominant form of phosphorus in the discharge with peaks in concentration in the mid-summer to early fall period. DOP concentrations are comparable or larger than PO_4 concentrations at all times of the year. In contrast to Trap Pond, the low PON/POC ratios are consistent with a terrestrial rather than aquatic origin of the particulate organic matter. The low observed loads of nitrogen and phosphorus reflect the small size of the watershed, the absence of substantial agricultural and domestic land uses, and the efficiency of total nitrogen attenuation and total phosphorus immobilization in wetland and forest settings.

There appears to be an inverse relationship between long-term trends in baseflow discharge and some nutrient concentrations at Mifflin Ditch during extended dry periods. This can best be seen in the final four months of the study, March to June 2004, when rainfall and discharge were very low and the concentrations of all dissolved and particulate species, except NO_3, increased with decreasing discharge. This relationship indicates that loads from this watershed remain relatively constant in spite of major changes in rainfall and discharge.

Silicate (Si) and baseflow discharge are also negatively correlated ($r = 0.79$). Because the underlying aquifer matrix is dominated by quartz sand and silicate concentrations in ground water increase with longer ground-water residence times, the negative correlation between Si and baseflow discharge indicates shorter ground-water residence times during high baseflow periods. Although this relationship between Si and discharge is observed in several streams in the Inland Bays watershed (Andres, 2002a, 2002b), Mifflin Ditch is the only station in this study showing this relationship.

Nanticoke River at Bridgeville, Del. (USGS DE01487000)

The Nanticoke River at Bridgeville is the largest tributary sampled in this study and drains a dominantly agricultural watershed with additional forest and wetland areas (Table 6). Above the gaging station, the river has a wide forested and wetland riparian boundary that serves to moderate discharge and nutrient loads from this watershed. The river flows consistently through the year with slight peaks in discharge during the late-winter/early-spring; the strong seasonal patterns in discharge and nutrient levels seen at Trap Pond are largely absent from this site (Fig. 5).

The principal form of nitrogen in the discharge is NO_3 and concentrations are only slightly higher in the winter and spring than during the summer (250 vs. 325 μM N). This suggests a consistent source of water, presumably from ground-water discharge, and that within-stream processes have a limited effect on the concentrations of N compounds. Due to the large size of the watershed, the nitrogen loads are high at all times of the year, with slightly lower loads reflecting lower discharge during the spring and summer months.

NO_3 concentrations in baseflow are negatively correlated with DOC ($r = 0.72$), PP ($r = 0.64$), and PO_4 ($r = 0.81$) concentrations. Because DOC, PP, and PO_4 concentrations in local ground water are typically much lower than that in surface waters, this indicates another source for these constituents, most likely discharge from or through the riparian boundary or exchange with the hyporheic zone.

PP loads are often comparable or only slightly less than TDP loads. PO_4 and DOP contribute approximately equally to the TDP loads. Consistent with the agricultural land use and presumed origin of most of the waters in this tributary, there is a large excess of DIN over PO_4 at all times of the year, although there is a seasonal pattern with DIN/PO_4 ratios decreasing during the spring and summer months. Both the PON/POC (« 0.15) and PP/POC (« 0.01) ratios indicate the allochthonous terrestrial origin of the particulate matter collected at this station.

Total suspended solids (TSS) and associated particulate N, P, and C loads increased slightly with decreasing flow during the last four months of the study. Although this

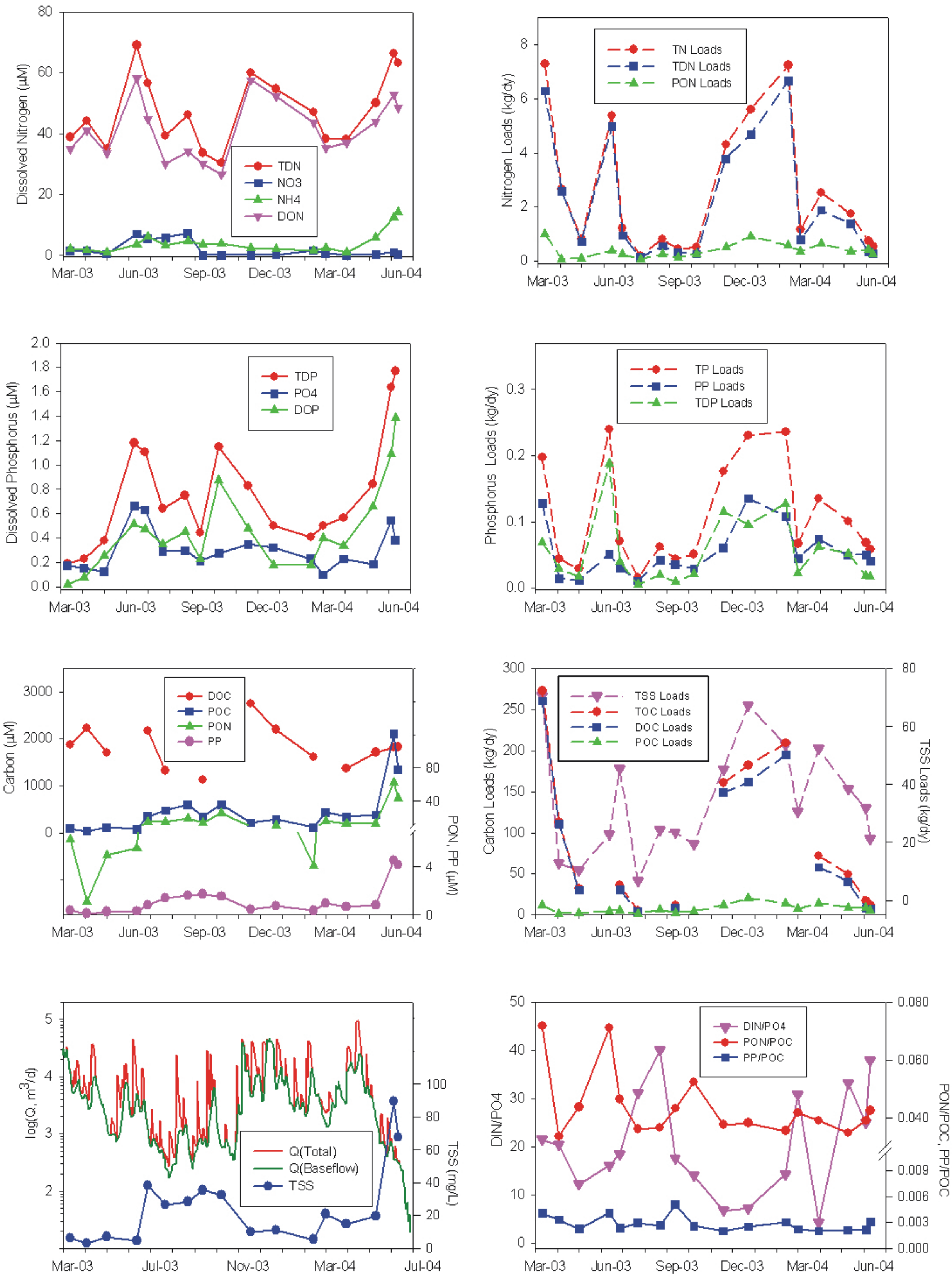

Figure 4. Nutrient (µM) and suspended solids (mg/L), instantaneous loads at baseflow (kg/d), and discharge (m^3/d) determined at Mifflin Ditch near Georgetown, Del.

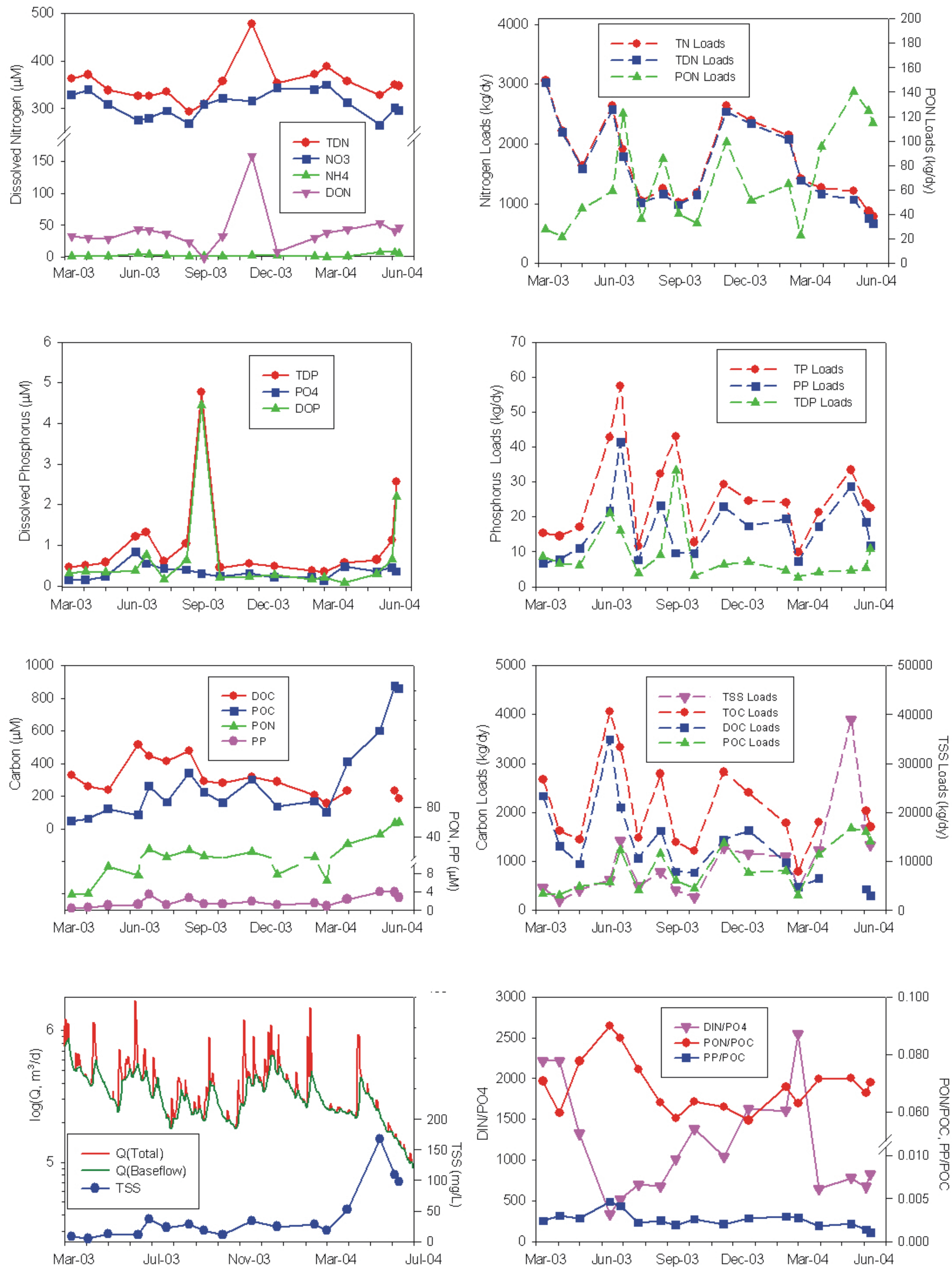

Figure 5. Nutrient (µM) and suspended solids (mg/L), instantaneous loads at baseflow (kg/d), and discharge (m^3/d) determined at Nanticoke River at Bridgeville, Del.

indicates that baseflow loads remain relatively constant and relatively insensitive to local rainfall, this effect is moderated at the Nanticoke site relative to smaller wetland sites, such as Mifflin Ditch.

The wetlands and forested areas, particularly those in the riparian boundaries of this watershed, serve to moderate and minimize the loads of phosphorus and, to a lesser extent, nitrogen from the watershed.

Herring Run Tributary at Seaford, Del. (USGS DE01487195)

The drainage ditch sampled as part of this study drains a dominantly commercial/residential watershed (Table 6). The stream flows only minimally during periods between rainstorms and, as a result, baseflow loads cannot be reliably calculated (see results above; Fig. 6). In contrast to Trap Pond, the maximum TDN and TDP concentrations (100 - 120 μM N and 6 - 8 μM P) in the baseflow waters occur in the spring and summer, a period when dissolved organic species predominate. PON/POC ratios are consistent with a largely terrestrial source of suspended organic matter discharging from the watershed. PP/POC are higher than the level in terrestrial or aquatic detritus, suggesting a local inorganic contribution to the PP, perhaps associated with iron oxyhydroxide suspensions seen at this site during low flow periods at all times of the year. When this stream flows, total nitrogen concentrations are comparable to those from agricultural watersheds and total phosphorus concentrations are higher than found elsewhere in the Nanticoke River/Chesapeake Bay watershed.

Discharge is negatively correlated with almost all chemical species and TSS during baseflow periods at Herring Run. Of these, the potentially significant correlations with NH_4 ($r = 0.74$), TDP ($r = 0.67$), PP ($r = 0.73$), TSS ($r = 0.78$), and Si ($r = 0.81$) indicate that shallow ground water flows, when present at high discharge, serve to dilute the higher concentrations found in the more constant, albeit small, deeper groundwater discharges.

Dukes and Jobs Ditch near Laurel, Del. (USGS DE01487698)

Dukes and Jobs Ditch drains a heavily ditched and primarily agricultural watershed (Table 6). Discharge between storms is small except during the winter and early spring when local water tables are highest (Fig. 7). NO_3 is the dominant form of nitrogen, and TDN concentrations (700 – 800 μM N) are the highest found at any site studied. These observations are consistent with a primary source of water and nitrogen from the oxic upper zones of local (agricultural) soils, and they discharge primarily through (shallow and short) ground-water pathways to the ditch. As a result of this mechanism of water transport, particles are largely absent from the discharge (except for one sample that aspirated sand, early in the study). Due to the transport of input water through the soil and surficial aquifer, phosphate (PO_4) concentrations are very high (up to 3.5 μM P at some times) compared to other surface water sources in the Nanticoke watershed. The high DIN/PO_4 ratios are consistent with high agricultural inputs to this ditch through discharge from the soil zone and from shallow ground water.

Based on PON/POC ratios, the organic matter that discharges through this site is primarily of terrestrial origin. The high load of nitrogen from this watershed reflects local agricultural management practices.

PO_4, DOP, and TDP appear to increase in concentration during the period of low flow at the end of the study. This effect is not seen for any other constituent at this site. Increases in these components may reflect changes in hyporheic exchange of TDP compounds due to the increased exposure of the ditch bottom and sand bars during this low-flow period.

Discharge is positively correlated with NH_4 ($r = 0.66$) and DOC ($r = 0.60$) indicating that groundwater is in contact with sources of NH_4 and labile organic carbon (possibly organic fertilizers), presumably in soils or subsoils, during periods of higher water table, higher baseflow, and shorter groundwater and soil residence times.

Stormflow Discharge and Water Quality

Table 8 shows that there are small spatial differences in precipitation amounts between Georgetown, Greenwood, and Jones Crossroads (DSWA) weather stations (Fig. 1) during many storm sampling events. The average difference between Georgetown and Greenwood is approximately -0.06 cm, between Georgetown and DSWA is approximately 0.42 cm, and between Greenwood and DSWA is 0.81 cm. The greatest spatial variability in precipitation occurred during storm SD (Oct. 26-29, 2003).

Tables 9 and 10 show that many of the storm events sampled during this study had relatively small effects on stream hydrographs. Peak flow during the storms was often less than 50 percent greater than baseflow at the beginning of the storm. This is the case for five of the six storms for the Nanticoke River, and for four of the six storms for Trap Pond Outlet and Dukes and Jobs Ditch. Table 10 also shows that peak flow during the storms was often less than monthly mean flow or within one order of magnitude of monthly mean flows.

The conclusion of this analysis is that this project sampled primarily small (stormflow < baseflow) and medium-sized (stormflow ≥ baseflow) storm events. As a result, we are uncertain of the impact of large storms (stormflow » baseflow) on discharge and loads from the Nanticoke River watershed in Delaware to the Chesapeake Bay. These unsampled large storms are likely to have significant consequences for loads. The use of volume-weighted storm concentration based on the small- and medium-sized storms that occurred during the study period to estimate the loads from large storms would have a greater and unquantifiable uncertainty. Our estimates of monthly, quarterly, and annual storm, and total loadings are not well constrained for periods when large storms occur.

Total Loads

For the purposes of monthly and annual loading computations, daily mean streamflows were classified as either “all baseflow” or “all stormflow” periods. Flow for a particular day is classified as “stormflow” when stormflow from the hydrograph separation is greater than 5 percent of total flow.

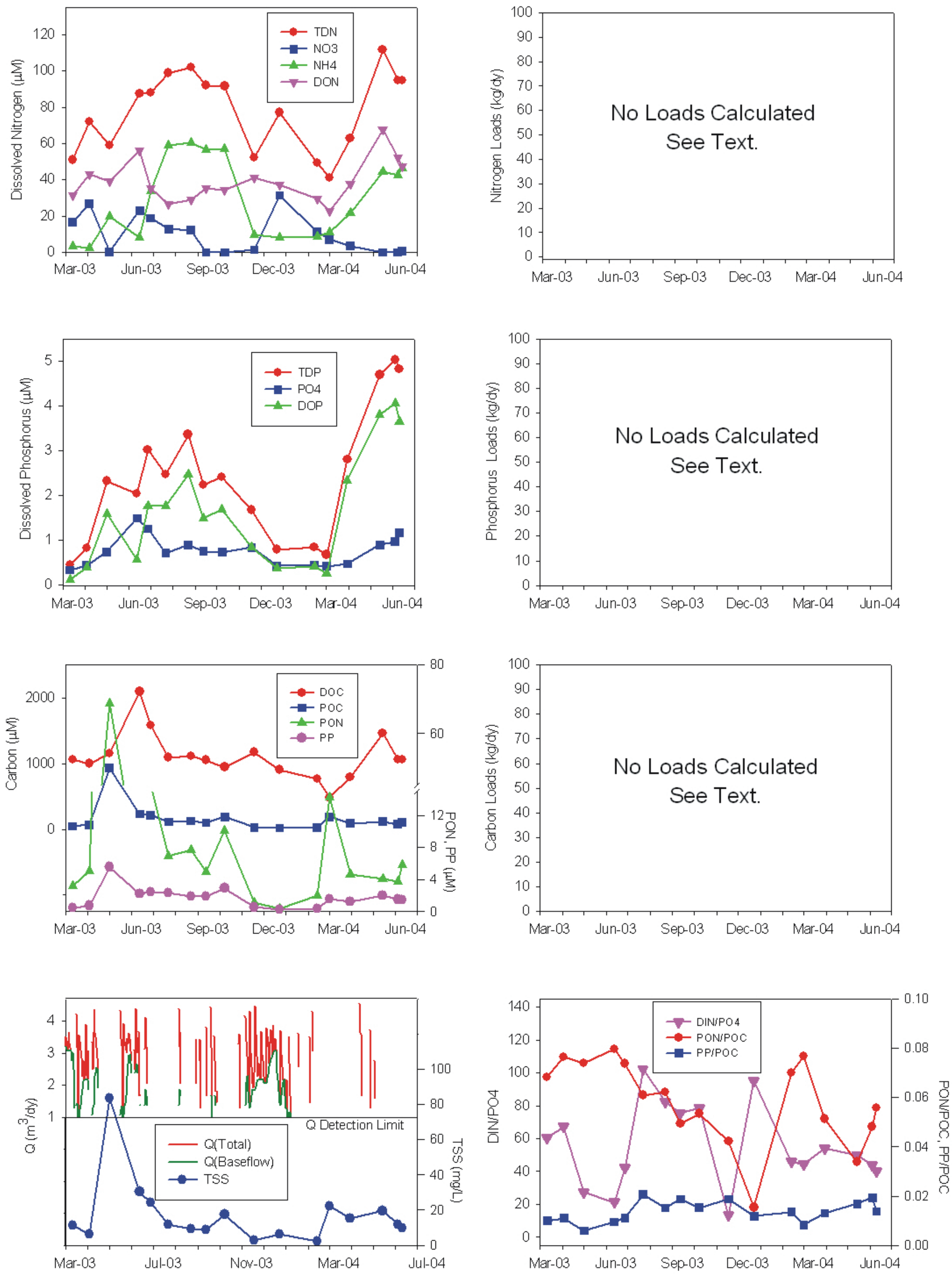

Figure 6. Nutrient (µM) and suspended solids (mg/L), instantaneous loads at baseflow (kg/d), and discharge (m^3/d) determined at Herring Run Tributary at Seaford, Del. Baseflow loads could not be calculated at this site due to poor discharge gaging at low flow (see text).

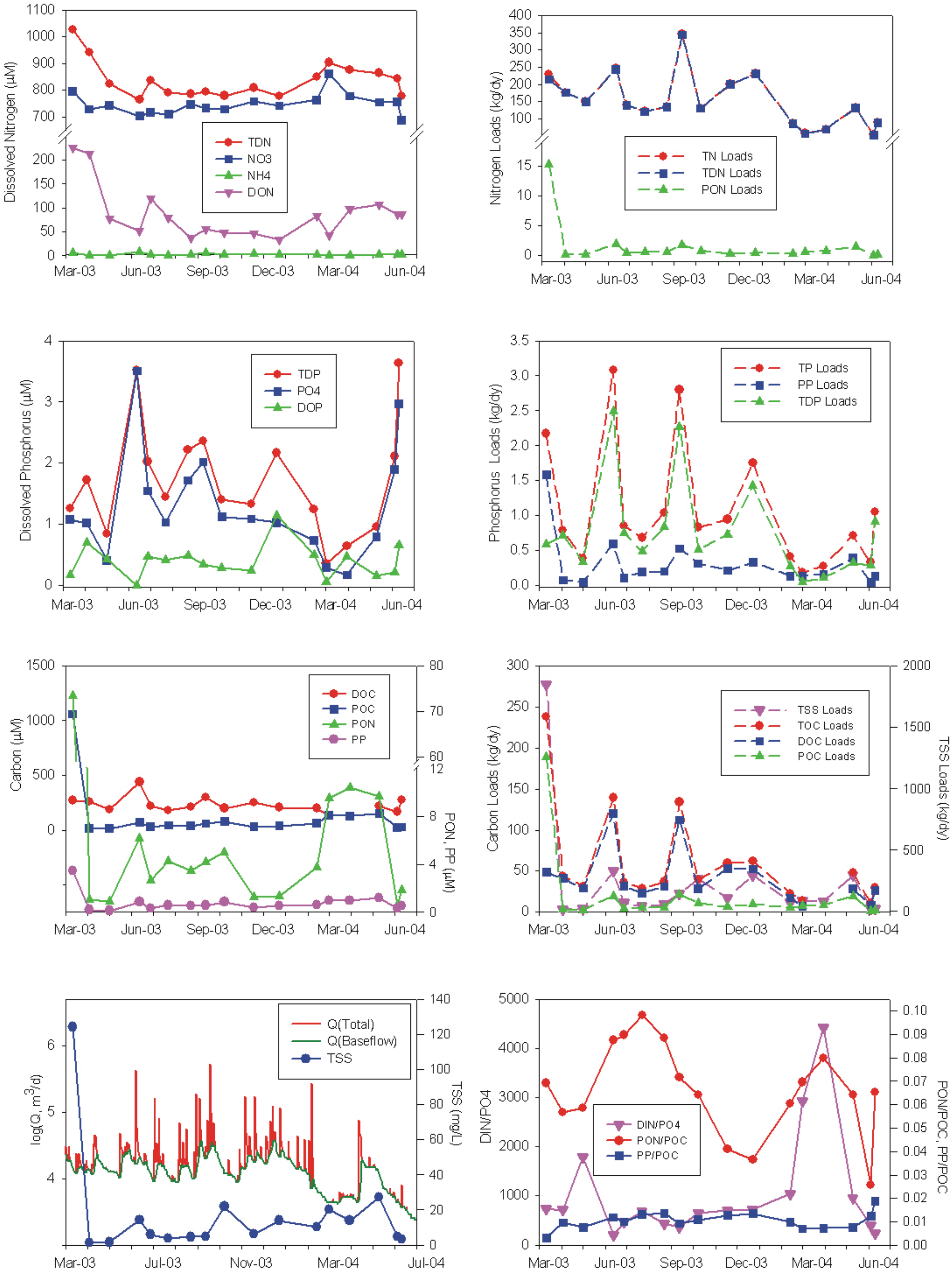

Figure 7. Nutrient (µM) and suspended solids (mg/L), instantaneous loads at baseflow (kg/d), and discharge (m³/d) determined at Dukes and Jobs Ditch near Laurel, Del.

Table 8. Precipitation amounts (in cm) recorded at Georgetown, Greenwood, and Jones Crossroads weather stations during sampled storm events.

Storm	Date	Georgetown	Greenwood**	Jones Crossroads***
SA	April 25-27, 2003	0.79	0.64	0.64
	May 21-23, 2003	2.72	1.47	2.01
SB	July 9-11, 2003	2.54	1.57	3.40
SC	Sept. 12-14, 2003	3.20	4.04	2.41
	Sept. 23-25, 2003	2.03	2.03	2.13
SD	Oct. 26-29, 2003	5.05	8.36	4.75
	Nov. 19-21, 2003	3.96	3.89	3.58
SE	March 30-April 2, 2004	1.55	1.52	1.09
SF	June 5-6, 2004	1.12	1.47	1.07

**See Figure 1 for locations. **Daniel and Connie Swartzentruber, personal communication (http://www.udel.edu/leathers); ***Dan Fluman, (Delaware Solid Waste Authority), personal communication.*

Table 9. Comparison of stormflow and baseflow discharge for sampled storms.

Storm	Trap Pond Outlet	Mifflin Ditch	Nanticoke River	Herring Run Tributary	Dukes and Jobs Ditch
SA	23	58	2	~100	3
SB	54	39	25	~100	83
SC	65	49	55	~100	49
SD	46	41	22	~100	90
SE	42	55	14	~100	22
SF	19	17	25	No Data	38

Note: Size is reported as a percentage and computed as 100 - (100 x baseflow/peakflow). Baseflow is evaluated just prior to the first storm sample. One hundred percent indicates that there was no measured baseflow prior to the storm event.

Table 10. Ratios of peak instantaneous flow during sampled storm events to monthly mean flow.

Storm	Trap Pond Outlet (24)	Mifflin Ditch (3)	Nanticoke River (62)	Herring Run Tributary	Dukes and Jobs Ditch (3)
SA	0.85	0.28	1.21	No Data	1.01
SB	2.64	3.47	3.29	No Data	10.70
SC	2.42	0.96	0.72	No Data	1.79
SD	2.47	1.98	1.91	No Data	17.22
SE	0.68	1.15	0.63	No Data	0.50
SF	0.60	0.17	1.02	No Data	0.49

**Monthly mean flow data obtained from U.S. Geological Survey National Water Information System (NWIS). The number of years of record for each station is shown in parenthesis following the station name. NWIS does not contain any monthly mean flow data for Herring Run Tributary.*

Flow for a particular day is classified as "all baseflow" when storm flow from the hydrograph separation is less than 5 percent of total flow. Daily mass loadings of dissolved and particulate constituents are computed from the mean daily discharges and the estimated concentrations of constituents and these estimated daily loadings were summed to give monthly loadings for each of the Nanticoke River subwatersheds. Quarterly and annual loadings are calculated from these results. Flow-weighted average concentrations are computed as the total mass divided by the total flow during a specified time period.

Table 11 shows flow-weighted average concentrations for each storm and each quarterly period at every station. The volume-weighted average concentrations of Storms SA and SF were chosen to represent the loading characteristics of the Spring Quarter (April, May, and June). The average concentrations of Storm SB were chosen to represent the Summer Quarter (July, August, and September). The volume-weighted average of the concentrations of Storms SC and SD was taken as representative of the Fall Quarter (October, November, December). Storm SE was chosen to represent the Winter Quarter (January, February, March). Concentrations of N and P compounds in stormflow tend to follow the same seasonal patterns as those in baseflow. Total loads by station computed for monthly and annual periods are shown in Table 12. Quarterly total, baseflow and stormflow loads are shown in Table 13. The observed variation of monthly and quarterly loads tends to be more closely related

Table 11. Volume-weighted average concentrations for individual storms and for quarterly periods at each sampling site*. TDN, PON – total dissolved and particulate organic nitrogen; TDP, PP – total dissolved and particulate phosphorus; DOC, POC – dissolved and particulate organic carbon; TSS – total suspended solids; Si – Silica. All concentrations are μM with the exception of TSS (mg/L). Quarters: Spring = Storms SA and SF; Summer = Storm SB; Fall = Storms SC and SD; Winter = Storm SE.

Site	Storm	TDN	PON	TDP	PP	DOC	POC	TSS	Si
Trap Pond Outlet	SA	217	7.98	5.42	2.39	955	93	457	327
	SB	41	38.8	0.96	2.88	801	275	12.6	139
	SC	45	53.2	1.16	3.22	714	410	15.8	260
	SD	79	22.3	1.48	1.80	649	201	9.68	285
	SE	127	8.22	0.67	0.99	535	112	6.65	149
	SF	67	33.9	2.14	2.45	784	239	12.2	219
	Quarter								
	Spring	252	7.03	2.44	0.97	973	96	6.0	168
	Summer	41	38.79	0.96	2.88	801	275	12.6	139
	Fall	61	38.70	1.31	2.56	684	312	13.0	272
	Winter	127	8.22	0.67	0.99	535	112	6.65	149
Mifflin Ditch	SA	43	3.39	0.41	0.20	2251	47	3.6	207
	SB	46	11.5	0.85	0.92	1126	225	14.0	233
	SC	36	2.59	0.82	0.68	1338	176	10.2	333
	SD	62	16	1.01	1.11	2839	580	27.2	301
	SE	42	1.95	0.38	0.35	1911	111	5.66	248
	SF	51	39.3	0.46	2.90	1394	898	59.8	257
	Quarter								
	Spring	43	5.26	0.41	0.34	2206	91	6.6	210
	Summer	46	11.5	0.85	0.92	1126	225	14.0	233
	Fall	49	8.69	0.93	0.89	2063	363	18.2	330
	Winter	42	1.95	0.38	0.35	1911	111	5.66	248
Nanticoke River	SA	312	8.86	0.54	1.14	234	104	10.8	278
	SB	271	14.32	1.12	2.40	372	170	33.5	275
	SC	615	29.94	4.96	10.5	1186	379	2987	1538
	SD	370	9.08	0.55	1.33	289	139	12.6	307
	SE	378	14.92	0.60	1.63	224	220	31.7	297
	SF	363	34.52	1.03	3.21	247	467	161	311
	Quarter								
	Spring	334	19.88	0.75	2.03	239	260	75.3	292
	Summer	271	14.32	1.12	2.40	372	170	33.5	275
	Fall	336	10.06	0.66	1.52	373	152	14.0	310
	Winter	378	14.92	0.60	1.63	224	220	31.7	297
Herring Run Tributary	SA	35	1.14	0.51	0.40	445	34	3.58	25
	SB	48	13.7	1.01	1.93	450	120	12.5	16
	SC	34	13.1	1.56	1.75	486	166	15.9	31
	SD	40	7.27	2.16	1.64	723	118	18.3	38
	SE	31	3.81	0.65	0.55	217	69	7.74	10
	SF	84	11.1	1.93	1.64	730	156	25.1	76
	Quarter								
	Spring	84	10.95	1.91	1.63	727	154	24.82	75
	Summer	48	13.7	1.01	1.93	450	120	12.5	16
	Fall	37	10.2	1.86	1.70	603	143	17.1	34
	Winter	31	3.81	0.65	0.55	217	69	7.74	10
Dukes and Jobs Ditch	SA	850	1.07	0.83	0.10	216	17	1.83	299
	SB	449	9.38	11.1	1.79	504	73	18.2	186
	SC	485	2.17	11.0	1.32	288	29	309	449
	SD	439	18.8	18.5	3.65	742	255	50.1	167
	SE	867	0.36	0.58	0.34	213	40	4.04	342
	SF	772	2.87	4.07	0.58	302	44	6.47	334
	Quarter								
	Spring	831	1.50	1.61	0.22	237	24	2.94	307
	Summer	449	9.38	11.1	1.79	504	73	18.2	186
	Fall	518	15.2	16.1	3.02	694	208	40.0	212
	Winter	867	0.36	0.58	0.34	213	40	4.04	342

**See Table 3 for storm designations and dates. See text for a description of each quarter and how quarterly averages were calculated.*

Table 12. Provisional cumulative monthly and annual mass loads (kg) and discharge (m^3) at each sampling site April 1, 2003 to March 31, 2004. TDN, PON – total dissolved and particulate organic nitrogen; TDP, PP – total dissolved and particulate phosphorus; DOC, POC – dissolved and particulate organic carbon; TSS – total suspended solids; Si – Silica; Q – discharge.

Site	Period	TDN	PON	TDP	PP	DOC	POC	TSS	Si	Q
Trap Pond Outlet	April	1.09E+04	3.79E+02	2.32E+02	1.15E+02	4.11E+04	4.04E+03	2.09E+04	1.53E+04	3.55E+09
	May	8.19E+03	4.58E+02	1.84E+02	1.14E+02	3.15E+04	4.25E+03	2.45E+04	1.16E+04	2.53E+09
	June	6.39E+03	5.88E+02	1.54E+02	1.32E+02	2.64E+04	4.74E+03	2.76E+04	1.01E+04	2.25E+09
	July	4.54E+02	4.81E+02	2.42E+01	6.55E+01	6.05E+03	2.75E+03	9.33E+03	3.09E+03	6.54E+08
	August	3.26E+02	3.70E+02	2.20E+01	4.95E+01	4.82E+03	2.14E+03	6.75E+03	2.78E+03	5.35E+08
	September	1.20E+03	5.42E+02	5.91E+01	9.11E+01	1.07E+04	3.90E+03	1.42E+04	9.02E+03	1.17E+09
	October	3.90E+03	1.60E+03	1.44E+02	2.86E+02	2.12E+04	1.22E+04	4.65E+04	2.49E+04	3.40E+09
	November	7.64E+03	1.45E+03	1.75E+02	2.74E+02	2.51E+04	1.15E+04	4.52E+04	2.94E+04	4.70E+09
	December	4.51E+03	1.98E+02	6.40E+01	6.92E+01	1.07E+04	2.43E+03	1.23E+04	9.30E+03	2.04E+09
	January	5.20E+03	2.92E+02	6.45E+01	8.84E+01	1.60E+04	3.31E+03	1.65E+04	1.08E+04	2.64E+09
	February	2.31E+03	1.70E+02	2.66E+01	4.33E+01	5.70E+03	1.58E+03	7.72E+03	5.24E+03	1.17E+09
	March	2.87E+03	1.14E+03	1.71E+02	1.88E+02	2.44E+04	7.06E+03	3.04E+04	1.58E+04	2.73E+09
	Sum	5.10E+04	6.52E+03	1.15E+03	1.33E+03	1.99E+05	5.29E+04	2.32E+05	1.31E+05	2.463E+10
Mifflin Ditch	April	1.80E+02	2.01E+01	3.64E+00	2.83E+00	7.79E+03	3.17E+02	1.88E+03	1.70E+03	3.07E+08
	May	9.10E+01	1.08E+01	2.09E+00	1.50E+00	3.54E+03	1.62E+02	9.43E+02	8.43E+02	1.44E+08
	June	1.50E+02	1.98E+01	3.73E+00	2.74E+00	5.65E+03	3.04E+02	1.95E+03	1.37E+03	2.37E+08
	July	1.61E+01	4.60E+00	6.48E-01	7.83E-01	3.79E+02	8.61E+01	4.69E+02	1.62E+02	2.48E+07
	August	4.95E+01	1.35E+01	2.00E+00	2.37E+00	9.72E+02	2.39E+02	1.19E+03	5.12E+02	7.63E+07
	September	3.02E+01	1.06E+01	1.48E+00	1.66E+00	8.72E+02	2.50E+02	1.10E+03	4.34E+02	4.84E+07
	October	3.92E+02	7.09E+01	1.61E+01	1.51E+01	1.41E+04	2.40E+03	9.94E+03	5.10E+03	5.72E+08
	November	6.52E+02	9.93E+01	1.75E+01	1.80E+01	2.37E+04	2.78E+03	1.01E+04	6.16E+03	9.03E+08
	December	1.35E+02	1.35E+01	2.69E+00	2.88E+00	4.89E+03	3.94E+02	1.47E+03	1.25E+03	2.06E+08
	January	1.95E+02	1.70E+01	3.99E+00	4.04E+00	6.66E+03	5.46E+02	2.25E+03	2.08E+03	3.44E+08
	February	8.58E+01	2.34E+01	2.07E+00	3.70E+00	2.62E+03	5.38E+02	2.41E+03	9.24E+02	1.45E+08
	March	6.25E+02	4.56E+02	1.35E+01	7.35E+01	1.52E+04	8.99E+03	4.91E+04	6.30E+03	9.14E+08
	Sum	1.98E+03	3.03E+02	5.59E+01	5.56E+01	7.12E+04	8.01E+03	3.40E+04	2.05E+04	3.007E+09
Nanticoke River	April	7.58E+04	2.47E+03	2.99E+02	6.05E+02	4.58E+04	2.84E+04	5.03E+05	1.24E+05	1.58E+10
	May	5.99E+04	2.51E+03	3.04E+02	6.11E+02	4.38E+04	2.77E+04	5.31E+05	1.05E+05	1.26E+10
	June	7.78E+04	3.84E+03	5.30E+02	1.08E+03	7.48E+04	4.08E+04	7.63E+05	1.43E+05	1.73E+10
	July	4.27E+04	2.09E+03	2.88E+02	6.36E+02	4.80E+04	2.22E+04	2.91E+05	7.97E+04	9.71E+09
	August	3.88E+04	2.29E+03	3.56E+02	7.10E+02	4.81E+04	2.76E+04	2.91E+05	7.39E+04	9.53E+09
	September	3.71E+04	1.15E+03	1.57E+02	3.29E+02	2.72E+04	1.55E+04	1.07E+05	6.00E+04	7.20E+09
	October	7.83E+04	2.61E+03	2.75E+02	7.37E+02	6.07E+04	3.52E+04	3.03E+05	1.28E+05	1.48E+10
	November	9.16E+04	2.70E+03	3.31E+02	8.21E+02	6.99E+04	3.65E+04	3.90E+05	1.60E+05	1.80E+10
	December	5.79E+04	1.65E+03	1.65E+02	4.91E+02	3.35E+04	2.21E+04	3.05E+05	9.95E+04	1.11E+10
	January	6.48E+04	2.02E+03	1.72E+02	5.53E+02	2.99E+04	2.56E+04	3.34E+05	1.06E+05	1.29E+10
	February	4.05E+04	1.97E+03	1.17E+02	4.07E+02	1.87E+04	2.42E+04	2.78E+05	6.41E+04	7.62E+09
	March	5.67E+04	5.54E+03	2.82E+02	1.10E+03	2.62E+04	6.54E+04	1.44E+06	9.33E+04	1.16E+10
	Sum	6.65E+05	2.53E+04	2.99E+03	6.98E+03	5.00E+05	3.06E+05	4.10E+06	1.14E+06	1.366E+11
Herring Run Tributary*	April	4.89E+01	6.38E+00	2.45E+00	2.09E+00	3.67E+02	7.71E+01	1.04E+03	8.82E+01	4.25E+07
	May	6.72E+01	8.78E+00	3.39E+00	2.89E+00	5.00E+02	1.06E+02	1.42E+03	1.21E+02	5.64E+07
	June	6.17E+01	8.08E+00	3.11E+00	2.65E+00	4.59E+02	9.76E+01	1.31E+03	1.11E+02	5.35E+07
	July	2.34E+01	6.74E+00	1.10E+00	2.09E+00	1.89E+02	5.04E+01	4.39E+02	1.56E+01	3.44E+07
	August	2.50E+01	7.20E+00	1.17E+00	2.24E+00	2.02E+02	5.39E+01	4.69E+02	1.67E+01	3.68E+07
	September	9.72E+00	2.71E+00	1.09E+00	9.93E-01	1.37E+02	3.23E+01	3.22E+02	1.81E+01	1.86E+07
	October	5.05E+01	1.40E+01	5.62E+00	5.13E+00	7.11E+02	1.67E+02	1.66E+03	9.49E+01	9.94E+07
	November	2.55E+01	6.05E+00	2.44E+00	2.21E+00	3.24E+02	7.43E+01	7.40E+02	4.51E+01	4.84E+07
	December	4.10E+00	5.00E-01	1.89E-01	1.60E-01	2.48E+01	7.81E+00	7.27E+01	2.67E+00	9.25E+06
	January	1.06E+01	1.31E+00	4.92E-01	4.16E-01	6.36E+01	2.04E+01	1.89E+02	6.67E+00	2.57E+07
	February	2.13E-02	2.61E-03	9.86E-04	8.33E-04	1.27E-01	4.08E-02	3.79E-01	1.34E-02	4.81E+04
	March	6.08E+01	7.99E+00	3.07E+00	2.62E+00	4.52E+02	9.65E+01	1.29E+03	1.09E+02	5.24E+07
	Sum	3.27E+02	6.17E+01	2.11E+01	2.09E+01	2.98E+03	6.87E+02	7.67E+03	5.19E+02	425049380
Dukes and Jobs Ditch	April	6.94E+03	9.45E+00	2.49E+01	3.09E+00	1.56E+03	1.42E+02	1.24E+03	5.03E+03	5.85E+08
	May	7.24E+03	1.98E+01	3.40E+01	6.06E+00	1.98E+03	2.30E+02	3.03E+03	5.70E+03	6.24E+08
	June	1.15E+04	3.44E+01	6.13E+01	1.04E+01	3.24E+03	3.90E+02	5.27E+03	9.00E+03	1.02E+09
	July	5.39E+03	7.34E+01	1.72E+02	2.94E+01	3.32E+03	5.17E+02	9.41E+03	4.70E+03	6.75E+08
	August	5.64E+03	8.39E+01	2.07E+02	3.44E+01	3.89E+03	5.89E+02	1.11E+04	4.84E+03	7.42E+08
	September	4.06E+03	4.50E+01	7.59E+01	1.87E+01	1.79E+03	5.61E+02	1.05E+04	3.36E+03	4.06E+08
	October	8.87E+03	1.54E+02	3.58E+02	6.91E+01	6.73E+03	1.87E+03	3.05E+04	7.60E+03	1.05E+09
	November	1.11E+04	1.17E+02	2.80E+02	5.58E+01	5.87E+03	1.55E+03	2.62E+04	9.29E+03	1.13E+09
	December	6.64E+03	1.42E+01	2.50E+01	8.64E+00	1.42E+03	3.13E+02	5.64E+03	5.59E+03	5.64E+08
	January	6.19E+03	1.35E+01	1.18E+01	7.22E+00	1.25E+03	3.23E+02	3.54E+03	4.97E+03	5.38E+08
	February	1.88E+03	1.50E+01	4.92E+00	3.71E+00	2.48E+02	1.88E+02	1.99E+03	1.45E+03	1.52E+08
	March	5.79E+03	4.41E+01	3.99E+01	1.26E+01	1.29E+03	5.41E+02	6.58E+03	4.77E+03	5.14E+08
	Sum	7.54E+04	5.80E+02	1.25E+03	2.47E+02	3.13E+04	6.67E+03	1.08E+05	6.15E+04	7.49E+09

**Baseflow estimated for only those periods for which discharge measurements were available (see text) These data represent minimum loadings.*

Table 13. Provisional cumulative mass total, baseflow, and stormflow loads (kg) and discharge (m^3) at each sampling site by quarter*. TDN, PON – total dissolved and particulate organic nitrogen; TDP, PP – total dissolved and particulate phosphorus; DOC, POC – dissolved and particulate organic carbon; TSS – total suspended solids; Si – Silica; Q – discharge (in cubic meters). Mifflin Ditch Quarters: Spring = April 1 through June 30, 2004; Summer = July 1 through September 30, 2004; Fall = October 1 through December 31, 2004; Winter = January 1 through February 28, 2005.

	Quarter	Loading	TDN	PON	TDP	PP	DOC	POC	TSS	Si	Q
Trap Pond Outlet	Spring	Total	2.55E+04	1.42E+03	5.70E+02	3.61E+02	9.90E+04	1.30E+04	7.30E+04	3.70E+04	8.33E+09
		Base	3.04E+03	7.38E+02	8.74E+01	1.61E+02	2.38E+04	5.35E+03	3.35E+04	6.60E+03	1.83E+09
		Storm	2.25E+04	6.86E+02	4.82E+02	2.01E+02	7.52E+04	7.68E+03	3.95E+04	3.04E+04	6.49E+09
	Summer	Total	1.84E+03	1.73E+03	9.94E+01	2.49E+02	2.52E+04	1.04E+04	3.59E+04	1.42E+04	2.79E+09
		Base	4.96E+02	5.68E+02	3.11E+01	6.28E+01	5.30E+03	3.18E+03	8.74E+03	4.23E+03	6.41E+08
		Storm	1.35E+03	1.16E+03	6.83E+01	1.86E+02	1.99E+04	7.26E+03	2.71E+04	9.99E+03	2.15E+09
	Fall	Total	1.27E+04	3.59E+03	3.78E+02	6.51E+02	5.70E+04	2.77E+04	1.06E+05	6.33E+04	9.27E+09
		Base	6.24E+03	5.39E+02	1.37E+02	1.91E+02	5.84E+03	6.00E+03	2.89E+04	1.77E+04	2.83E+09
		Storm	6.50E+03	3.05E+03	2.41E+02	4.60E+02	5.11E+04	2.17E+04	7.70E+04	4.56E+04	6.44E+09
	Winter	Total	1.20E+04	6.60E+02	1.55E+02	2.01E+02	3.24E+04	7.32E+03	3.66E+04	2.54E+04	5.85E+09
		Base	6.70E+03	2.88E+02	8.94E+01	1.05E+02	1.28E+04	3.16E+03	1.61E+04	1.26E+04	2.78E+09
		Storm	5.32E+03	3.72E+02	6.56E+01	9.55E+01	1.96E+04	4.16E+03	2.05E+04	1.28E+04	3.07E+09
Mifflin Ditch	Spring	Total	4.36E+02	5.29E+01	9.84E+00	7.42E+00	1.75E+04	8.19E+02	4.96E+03	4.05E+03	7.12E+08
		Base	8.19E+01	9.09E+00	2.23E+00	1.11E+00	2.32E+03	1.63E+02	1.07E+03	6.28E+02	1.26E+08
		Storm	3.54E+02	4.38E+01	7.61E+00	6.31E+00	1.52E+04	6.56E+02	3.90E+03	3.42E+03	5.86E+08
	Summer	Total	1.70E+02	4.43E+01	7.05E+00	8.08E+00	4.15E+03	9.14E+02	4.50E+03	1.93E+03	2.66E+08
		Base	1.61E+01	8.79E+00	7.17E-01	1.41E+00	2.63E+02	1.75E+02	9.49E+02	2.14E+02	3.00E+07
		Storm	1.54E+02	3.55E+01	6.34E+00	6.67E+00	3.89E+03	7.39E+02	3.55E+03	1.71E+03	2.36E+08
	Fall	Total	1.13E+03	1.88E+02	3.69E+01	3.65E+01	4.06E+04	5.69E+03	2.26E+04	1.24E+04	1.60E+09
		Base	4.09E+02	8.09E+01	1.02E+01	1.10E+01	1.44E+04	1.76E+03	6.19E+03	2.95E+03	5.23E+08
		Storm	7.16E+02	1.07E+02	2.67E+01	2.55E+01	2.62E+04	3.93E+03	1.64E+04	9.41E+03	1.08E+09
	Winter	Total	4.10E+02	5.36E+01	8.63E+00	1.05E+01	1.39E+04	1.46E+03	6.08E+03	4.19E+03	6.87E+08
		Base	1.46E+02	3.23E+01	3.39E+00	4.36E+00	3.84E+03	7.08E+02	2.62E+03	1.09E+03	2.31E+08
		Storm	2.64E+02	2.13E+01	5.25E+00	6.14E+00	1.01E+04	7.56E+02	3.46E+03	3.10E+03	4.56E+08
Nanticoke River	Spring	Total	2.13E+05	8.82E+03	1.13E+03	2.30E+03	1.64E+05	9.68E+04	1.80E+06	3.72E+05	4.57E+10
		Base	1.21E+05	3.34E+03	6.53E+02	1.03E+03	1.05E+05	3.57E+04	3.41E+05	2.08E+05	2.56E+10
		Storm	9.26E+04	5.48E+03	4.80E+02	1.27E+03	5.95E+04	6.12E+04	1.46E+06	1.64E+05	2.02E+10
	Summer	Total	1.24E+05	6.29E+03	1.21E+03	1.96E+03	1.39E+05	7.28E+04	8.36E+05	2.33E+05	2.97E+10
		Base	6.68E+04	3.39E+03	7.11E+02	8.94E+02	7.25E+04	4.27E+04	3.63E+05	1.17E+05	1.48E+10
		Storm	5.77E+04	2.90E+03	4.98E+02	1.07E+03	6.65E+04	3.01E+04	4.72E+05	1.16E+05	1.48E+10
	Fall	Total	2.07E+05	6.46E+03	7.62E+02	1.89E+03	1.58E+05	8.72E+04	8.00E+05	3.48E+05	3.99E+10
		Base	1.06E+05	3.31E+03	3.32E+02	8.85E+02	6.70E+04	4.66E+04	4.63E+05	1.64E+05	1.88E+10
		Storm	1.01E+05	3.14E+03	4.30E+02	1.00E+03	9.07E+04	4.05E+04	3.37E+05	1.84E+05	2.11E+10
	Winter	Total	1.63E+05	5.64E+03	4.54E+02	1.45E+03	8.22E+04	7.20E+04	9.17E+05	2.70E+05	3.17E+10
		Base	1.22E+05	3.99E+03	3.09E+02	1.06E+03	6.11E+04	5.12E+04	6.68E+05	2.04E+05	2.36E+10
		Storm	4.15E+04	1.64E+03	1.45E+02	3.96E+02	2.12E+04	2.07E+04	2.49E+05	6.56E+04	8.03E+09
Herring Run Tributary*	Spring	Total	1.78E+02	2.32E+01	8.95E+00	7.63E+00	1.33E+03	2.81E+02	3.77E+03	3.20E+02	1.52E+08
		Base	5.26E-01	4.47E-02	9.23E-03	1.18E-02	7.06E+00	5.08E-01	1.75E+01	1.21E+00	5.65E+05
		Storm	1.77E+02	2.32E+01	8.94E+00	7.62E+00	1.32E+03	2.80E+02	3.75E+03	3.19E+02	1.52E+08
	Summer	Total	7.71E+01	2.21E+01	3.76E+00	6.92E+00	6.36E+02	1.69E+02	1.48E+03	5.41E+01	1.16E+08
		Base	1.26E-02	8.95E-04	2.25E-04	6.65E-04	1.20E-01	1.50E-02	1.12E-01	5.02E-02	9.95E+03
		Storm	7.71E+01	2.21E+01	3.76E+00	6.92E+00	6.36E+02	1.69E+02	1.48E+03	5.40E+01	1.16E+08
	Fall	Total	8.57E+01	2.27E+01	9.15E+00	8.34E+00	1.17E+03	2.74E+02	2.73E+03	1.58E+02	1.66E+08
		Base	2.01E+00	1.98E-02	3.43E-02	2.25E-02	2.42E+01	6.10E-01	1.06E+01	6.81E+00	2.04E+06
		Storm	8.37E+01	2.27E+01	9.11E+00	8.31E+00	1.15E+03	2.73E+02	2.71E+03	1.51E+02	1.64E+08
	Winter	Total	1.47E+01	1.81E+00	6.82E-01	5.76E-01	8.85E+01	2.82E+01	2.62E+02	9.36E+00	3.50E+07
		Base	3.90E-02	3.72E-04	5.10E-04	3.39E-04	4.11E-01	1.07E-02	2.07E-01	1.16E-01	3.85E+04
		Storm	1.47E+01	1.81E+00	6.82E-01	5.76E-01	8.81E+01	2.82E+01	2.62E+02	9.24E+00	3.50E+07
Dukes and Jobs Ditch	Spring	Total	2.57E+04	6.37E+01	1.20E+02	1.95E+01	6.78E+03	7.62E+02	9.54E+03	1.97E+04	1.76E+09
		Base	1.18E+04	3.85E+01	6.07E+01	1.15E+01	3.38E+03	4.22E+02	6.02E+03	9.41E+03	5.53E+08
		Storm	1.39E+04	2.52E+01	5.94E+01	8.04E+00	3.40E+03	3.40E+02	3.51E+03	1.03E+04	1.21E+09
	Summer	Total	2.39E+04	3.66E+02	8.79E+02	1.50E+02	1.68E+04	2.75E+03	5.09E+04	2.03E+04	3.18E+09
		Base	8.96E+03	4.64E+01	4.86E+01	1.46E+01	2.25E+03	5.03E+02	5.67E+03	7.86E+03	8.08E+08
		Storm	1.50E+04	3.19E+02	8.30E+02	1.35E+02	1.45E+04	2.25E+03	4.52E+04	1.24E+04	2.37E+09
	Fall	Total	2.40E+04	3.16E+02	7.14E+02	1.44E+02	1.44E+04	3.98E+03	6.71E+04	2.03E+04	2.59E+09
		Base	1.15E+04	3.42E+01	5.32E+01	1.79E+01	2.78E+03	5.78E+02	1.35E+04	1.01E+04	1.03E+09
		Storm	1.25E+04	2.82E+02	6.60E+02	1.26E+02	1.16E+04	3.40E+03	5.37E+04	1.01E+04	1.56E+09
	Winter	Total	1.47E+04	4.27E+01	4.18E+01	1.96E+01	2.91E+03	8.23E+02	1.12E+04	1.20E+04	1.25E+09
		Base	7.78E+03	3.90E+01	2.91E+01	1.34E+01	1.43E+03	5.48E+02	8.81E+03	6.52E+03	6.67E+08
		Storm	6.93E+03	3.65E+00	1.27E+01	6.21E+00	1.49E+03	2.75E+02	2.37E+03	5.50E+03	5.87E+08

**Baseflow estimated for only those periods for which discharge measurements were available (see text). These data represent minimum loadings. See text for a description of each quarter.*

Table 14. Annualized area-normalized loading rates in kg/ha-yr for Naticoke River, Trap Pond Outlet, and Mifflin Ditch.

Station	TDN	PON	TDP	PP	DOC	POC	TSS	Si
Trap Pond Outlet	11.8	1.51	0.27	0.31	46.1	12.2	53.5	30.4
Mifflin Ditch	5.08	0.78	0.14	0.14	18.3	20.6	87.5	52.8
Nanticoke River	34.1	1.30	0.15	0.36	25.6	15.7	210	58.5

to the variability of discharge than to the variability in concentrations.

Areally normalized loading rates for the Nanticoke River, Mifflin Ditch, and Trap Pond Outlet are shown in Table 14. Because of problems with water budgets described in a previous section, loading rates were not computed for Dukes and Jobs Ditch and Herring Run Tributary. The lower rates for TDN, TSS, and Si in Trap Pond Outlet are likely due to biological (uptake) and physical (settling) processes that occur in the impoundment. The TDN value for the Nanticoke River is comparable to that predicted by Ritter (1986) for portions of the Inland Bays watershed for a wet year. The TDN loading rate for Mifflin Ditch is two to six times lower than those observed in the Trap Pond and Nanticoke River watersheds and the DOC loading rate is four to six times higher than the other two stations. The low TDN loading rate and high DOC loading rate likely reflect the high proportion of forest and wetlands in the Mifflin Ditch watershed.

CONCLUSIONS

Nutrient concentrations and discharges were determined at five gaging sites in the Nanticoke River Watershed within Delaware in order to determine nitrogen, phosphorus, carbon, silica, and suspended solid loads. At one station, Herring Creek Tributary, baseflow discharges could not be accurately determined because the creek bed constantly changed in the course of the study, and as a result, the water levels fell below the gaging device on a number of occasions. Total discharge (baseflow + stormflow) could only be determined at the remaining four sites.

The water chemistry at each site reflects the local sources and transport from the land surface to the gaging site. At Trap Pond, the winter loads of TDN reflect the large local agricultural land use, but these loads are moderated by the biological processes in the pond during the spring, summer, and early fall. Mifflin Ditch waters have high organic concentrations, typical of wetland effluents, and limited amounts of NO_3 due to the lack of major agricultural sources in the watershed. There is little variability in water quality at the Nanticoke River at Bridgeville, reflecting the large size of the subwatershed and the relative importance of a constant discharge of ground water to this system. Herring Run Tributary flows little except during and after storms; this reflects its small size and the extent of impervious surfaces in its watershed. High levels of NO_3 and low levels of TSS at Dukes and Jobs Ditch reflect the extensive local agricultural land use and the transport of nutrients from land surfaces, by percolation, through the shallow subsurface to the Ditch.

At Dukes and Jobs Ditch, the amount of measured discharge exceeded the estimated discharge from hydrological models. In addition to the known problems with flow measurements at this site, this discrepancy could be due to the problems of delineating a watershed in areas with little topographic relief. The surface watershed and the ground watershed may not be coincident under these conditions. Ditching, a common practice in much of southern Delaware, can aggravate this problem by diverting precipitation falling on one watershed into another through the ditched drainage network.

At these two sites, the areal loads reflect the differences in the sources and transport of water in these watersheds. In contrast to the Nanticoke River at Bridgeville, the impoundment at Trap Pond serves to remove dissolved nutrients (primarily N) and suspended solids and to discharge more phosphorus (both particulate and dissolved) due to primary production and nutrient limitation.

The results of this study will be useful to DNREC in establishing total maximum daily load targets for the Nanticoke River Basin and elsewhere in the Delaware Coastal Plain and for designing management plans to meet these targets. In addition, this work will serve as a baseline for determining the future success of management plans for the Nanticoke River Watershed in Delaware and for the whole Chesapeake Bay system.

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