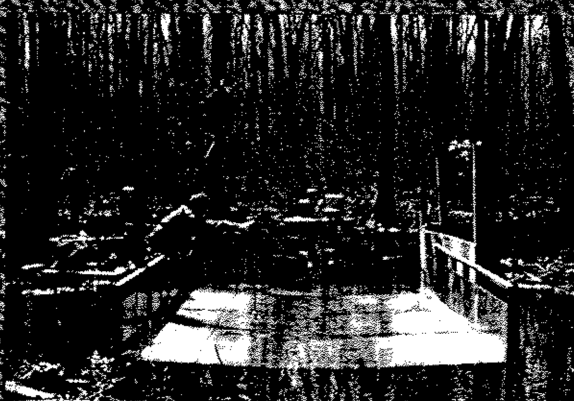
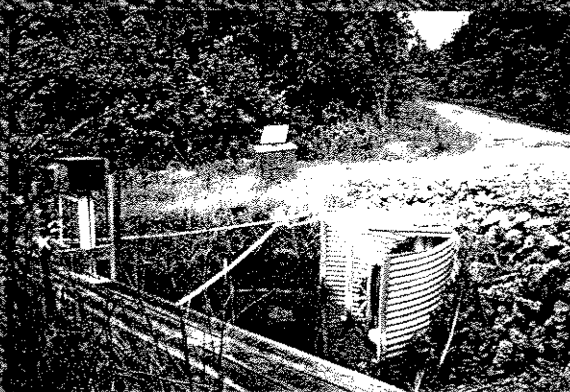
NC STATE UNIVERSITY

Hydrology and Water Quality of Forested Lands in Eastern North Carolina





North Carolina Agricultural Research Service
North Carolina State Universitry, Raleigh, North Carolina

Technical Bulletin 320
May 2003

Hydrology and Water Quality of Forested Lands in Eastern North Carolina

G. M. Chescheir, M. E. Lebo, D. M. Amatya,

J. Hughes, J. W. Gilliam, R. W. Skaggs, and R. B. Herrmann

Technical Bulletin 320
North Carolina State University
Raleigh, N.C.

Order from:
Department of Communication Services
Box 7603, NC State University
Raleigh, NC 27695-7603
$6.50 per copy (U.S. dollars only)

This research was conducted in the Department of Biological and Agricultural Engineering and the Department of Soil Science at North Carolina State University. The research was supported by funds from the U.S. EPA 319 program (Project No. EW9024 and EW8036), the Weyerhaeuser Company, the Water Resources Research Institute of the University of North Carolina (Project No. 70162), and the USDA NCREES/NRICGP (Project No. 98-35102-6493).

Cover Photography:

Top Center – Air photograph looking north from the Isaac Creek watershed site in Carteret County, NC.

Bottom Left – Enthusiastic hydrologist François Giraud measures water velocity at the outlet of the Washington County watershed near Plymouth, NC.

Bottom Right – Flow measurement and water quality sampling station at the outlet of the S4 watershed on the Parker Tract near Plymouth, NC.

Background - Color Infrared Digital Orthophoto Quarter Quadrangle (DOQQ) of forested land in the southern part of the Van Swamp watershed in Beaufort County, NC. The DOQQ was made available by the North Carolina Center for Geographic Information and Analysis.

CONTENTS

Executive Summary 3

Introduction 7

Site Descriptions 9

Full-Year Studies

Carteret County, Carteret 7 9

Carteret County, Isaac Creek 13

Jones County 15

Tyrrell County 16

Washington County 17

Parker Tract 18

Van Swamp and Pungo Lake 20

Croatan/Craven 40 21

Carteret County, Open Grounds Farm 21

Weyerhaeuser Multi-Tract Study 22

Baseline Hydrology 26

Carteret County, Carteret 7 26

Carteret County, Isaac Creek 27

Jones County 29

Tyrrell County 30

Washington County 31

Parker Tract 32

Van Swamp and Pungo Lake 33

Croatan/Craven 40 21

Summary of Hydrology 34

Nutrient Concentrations 38

Carteret County, Carteret 7 38

Carteret County, Isaac Creek 39

Jones County, Jones 5 40

Washington County 41

Parker Tract 42

Van Swamp and Pungo Lake 44

Croatan/Craven 40 45

Carteret County, Open Grounds Farm 46

Weyerhaeuser Multi-Tract Study 46

Mineral Soil Sites 47

Organic Soil Sites 49

Summary of Nutrient Concentrations 51

Nutrient Exports 58

Carteret County, Carteret 7 58

Carteret County, Isaac Creek 59

Jones County, Jones 5 60

Washington County 61

Parker Tract 61

Van Swamp and Pungo Lake 62

Summary of Nutrient Exports 62

Discussion 66

Effects of Soil 66

Effects of Drainage Intensity 68

Vegetation 71

Physiographic Location 72

Nutrient Exports 75

Literature Cited 77

Soil Series that Occurred on the Forested Sites 79

EXECUTIVE SUMMARY

Nonpoint sources of nutrients (NPS) are a widespread source of surface water pollution throughout the United States. Characterizing the sources of this NPS nutrient loading is challenging due to variation in land management practices, physiographic setting, site conditions such as soil type, and climatic variation. For nutrients, there is the added challenge of separating the influence of man's activities from natural processes that release essential nutrients. Although the effects of more invasive activities such as crop production and urban development on nutrient export have received considerable attention, the effects of varying regional conditions on forest nutrient export have not been well documented for eastern North Carolina. The purpose of this study was to assess baseline forest outflow characteristics in the coastal plain of eastern North Carolina. More than 100 site years of hydrology and water quality data spanning 25 years (1976 to 2000) have been compiled from research and monitoring studies both on stands with natural vegetation and on tracts managed for timber production. The study included 41 watersheds located on poorly drained to very poorly drained soils on flat divides between coastal streams. The watersheds ranged in area from 7.3 to 6,070 ha; 16 had natural forest vegetation, and 25 were intensively managed loblolly pine plantations. Hydrological and nutrient concentration data from the study sites are used to examine how variation among sites may be related to soil type, drainage intensity, vegetation, and physiographic setting.

Key Summary Points

- The median annual hydrologic response (outflow as a percentage of precipitation) among the sites was 31%, with an interquartile range of 26 to 35%.
- Seasonal variation in outflow was high. Outflow and hydrologic response at the sites were consistently higher in the winter quarter (January to March) than in spring (April to June), summer (July to September), or fall (October to December). Outflow exceeded 75 mm for all site years and exceeded 206 mm for half of the 84 winter seasons studied. On average, winter outflow was 51% of the annual total.
- Summer-fall outflow was variable among years due to high evapotranspiration (ET) and the variability of convective and tropical storms. Outflow was zero in 24% of summer quarters and 17% of fall quarters and exceeded 250 mm per quarter in other years. On average, summer and fall outflows were 12% and 19%, respectively, of the annual total.
- Nutrient concentrations in forest outflow were generally low for most study sites compared with typical values for other land uses. Listed are the mean seasonal concentrations of nutrient fractions in drainage from 50% of the study sites: less than 1.5 mg/L for total nitrogen (TN), less than 1.1 mg/L for organic N (Org-N), less than 0.1 mg/L for nitrate + nitrite N (NO_3-N), less than 0.1 mg/L for ammonium N (NH_4-N), and less than 0.07 mg/L for total phosphorus (TP).
- Annual TN exports from 75% of the study sites were less than 6.5 kg/ha, predominantly as Org-N at 18 of 21 sites. Annual TP export from all forest sites was less than 0.36 kg/ha. Maximum exports generally occurred during the winter.
- Concentrations of Org-N, TN, and TP were all consistently higher in drainage from organic soils than in drainage from mineral soils both for paired comparisons and for the overall database. Dissolved inorganic N (DIN) concentrations in drainage from organic soils were more variable than in drainage from mineral soils.
- The strong influence of soil type on forest outflow nutrient concentrations confounds the evaluation of other factors since a large fraction of the data is from watersheds with artificial drainage on organic soils.

Report Summary

The seasonal distribution of outflow from the various research sites was affected by weather patterns during the individual study period. The median annual hydrologic response (outflow as a percentage of precipitation) among the sites was 31%, which is consistent with the 40-year mean annual ratio of excess water (rainfall - potential ET) to rainfall from regional weather stations

(29 to 30%). Collectively, study sites in eastern North Carolina showed a consistent seasonal peak in outflow and hydrologic response in the winter; outflow exceeded 75 mm for all site years and exceeded 206 mm for half of the 84 winter (i.e., January to March) seasons studied. Outflow continued in the spring quarter for most sites and years (86 of 90), despite an average deficit of rainfall compared to potential ET in the region. Summer outflow was variable among years due to frequent low outflow in the late spring and high ET conditions early in the summer. No outflow occurred in 24% (22 of 90) of summer quarters; however, convective and tropical storms produced more than 250 mm of outflow in three summer seasons. Strong year-to-year variation in summer rainfall carried over into the fall quarter, with no outflow in 17% (15 of 90) of fall quarters and more than 250 mm of outflow in five others. By the end of the fall, soil water conditions were usually wet again due to decreased ET in cooler months.

Nutrient concentrations in forest outflow were generally low for most study sites compared with typical values for other land uses. Listed are the mean seasonal concentrations of nutrient fractions in drainage from 50% of the study sites: less than 1.5 mg/L for total N (TN), less than 1.1 mg/L for organic N (Org-N), less than 0.1 mg/L for nitrate + nitrite N (NO_3-N), less than 0.1 mg/L for ammonium N (NH_4-N), and less than 0.07 mg/L for total P (TP). For 75% of the study sites, mean seasonal concentrations in drainage water were less than 1.8 mg/L for TN, less than 1.5 mg/L for Org-N, less than 0.6 mg/L for NO_3-N, less than 0.22 mg/L for NH_4-N, and less than 0.08 mg/L for TP. Seasonal changes in nutrient concentrations were generally not consistent among sites for most of the measured nutrient fractions. The exception was consistently higher Org-N concentrations during summer months (13 of 16 sites), with a median value of 1.02 mg/L compared with 0.60 to 0.76 mg/L for other seasons. This seasonal pattern in Org-N concentrations was reflected in the TN concentrations; for 14 of 17 sites, highest TN concentrations occurred in the summer (median 1.43 mg/L) compared with fall through spring quarters (0.94 to 1.09 mg/L). For TP, the median concentration was also highest in the summer (0.064 mg/L) compared with other seasons (0.033 to 0.047 mg/L), but there was no consistent pattern across sites.

Nutrient exports from the forested lands reviewed in this study were generally low with the exception of the nitrogen exports from the Parker Tract in Washington County. Annual TN exports from 75% of the study sites were less than 6.5 kg/ha. Of the different N fractions, annual DIN exports were less than 2.9 kg/ha and Org-N exports were less than 4.0 kg/ha for 75% of the forested sites, with Org-N as the predominant form of N at most of the monitoring locations (18 of 21). For the three sites where Org-N was not the predominant form of N, annual DIN export accounted for 54 to 82% of average TN export, mainly as NO_3-N. Across all sites, the relative contribution of NO_3-N and NH_4-N forms to DIN varied by site, with each the predominant contributor to DIN in approximately half of the sites. However, sites with annual DIN export of greater than 1.1 kg/ha had NO_3-N as the dominant form. Annual TP export from all forested sites was less than 0.36 kg/ha.

Seasonal variation in outflow from the forested sites played an important role in seasonal nutrient export. For all of the study sites, maximum seasonal TN export occurred during the winter when maximum seasonal outflow also occurred. The same was true for TP export, with the exceptions of two sites where TP export was highest during the fall quarter. For the spring-fall quarters as a whole, nutrient exports did not show any consistent pattern across sites or among years. At some of the sites (e.g., Parker Tract S4 watershed), seasonal peaks in nutrient export occurred during summer or fall quarters associated with increased outflows following large tropical storms. High nutrient export for other sites (Tyrrell County sites and Pungo Lake) occurred during the spring quarter associated with years of high spring rainfall. Thus, variations in reported nutrient exports during the spring, summer, and fall quarters in the compiled studies largely reflected the seasonal distribution of rainfall during the study years rather than watershed characteristics.

Differences in four site characteristics may explain much of the observed variation in the hydrology and water quality of the forest sites surveyed in eastern North Carolina. Soil organic content (mineral vs. organic) appeared to be a dominant factor. The three other potentially important characteristics were site drainage intensity, forest vegetation, and physiographic location. Concentrations of Org-N, TN, and TP were all consistently higher in drainage from organic soils than in drainage from mineral soils both for paired comparisons and for the overall database. The impact of organic soils on the DIN concentrations was more variable. Four of the six highest DIN concentrations observed were from sites with organic soils, but four of the seven lowest DIN concentrations were also from sites with organic soils. This variable pattern in DIN among organic soil sites indicates that mineralization of Org-N to NH_4-N is controlled by factors other than the organic content of the soil.

The strong influence of soil type on forest outflow nutrient concentrations confounds the evaluation of other factors since a large fraction of the data is from watersheds with artificial drainage on organic soils. For example, TN concentration was higher, on average, from study sites with artificial drainage systems than from unditched sites. However, direct comparisons from paired sites actually contradict this pattern with lower TN from ditched sites. Comparisons of DIN and TP for ditched and unditched sites were also inconsistent for the three sets of paired watersheds available. Thus, general patterns evident in the compiled database relative to effects of artificial drainage on nutrient concentrations are at least partially a result of overall site differences for the two subgroups rather than an actual effect. It is likely that there is an interaction between the amount of organic matter present in the soil and drainage intensity, but the importance cannot be evaluated with available data. Evaluating the influence of vegetation is similarly confounded by a soil type bias in the overall database.

The TN and TP concentrations in water draining from the forested sites compiled in this review for the winter quarter, when data were available for more sites, were plotted geographically to evaluate whether concentrations were related to location. No consistent gradients in nutrient concentrations were identified. For the Neuse River basin, five of seven locations had TN concentrations of less than 1 mg/L, while one site had average winter TN concentrations as high as 2.2 mg/L. Low and high concentrations of TN and TP were also observed in other basins in eastern North Carolina. The variation of site characteristics, such as soil organic content, appeared to have a greater effect than site location. It is notable, however, that the two sites with the highest TN concentrations were located immediately east of the Suffolk Scarp on organic soils. Sandy horizons in the soil profile in those locations contribute to higher hydraulic conductivities at the Parker Tract in Washington County and the Morrison Tract in Gates County, which may be an important factor in the elevated TN concentrations observed.

For studies compiled in this review, seasonal hydrology was found to play an important role in nutrient export rates. In all of the studies reported, a large fraction of annual TN export occurred during the winter quarter when outflow was elevated. The same was true for TP export, with the exceptions of the Carteret D1 site and the Parker Tract F6 block; fall TP export was highest at those two sites. Another hydrologic factor affecting the seasonal distribution of nutrient exports was tropical storms and the excessive rainfall associated with them. Nutrient exports were higher in the summer or fall quarter when these large storms occurred. This was particularly true for TN and NO_3-N from the Parker Tract in 1996 when high outflow associated with three tropical storms flushed accumulated NO_3-N out of the soil profile during the fall quarter rather than during the winter. Elevated losses of TP were also reported during the summer and fall seasons at some sites. Spring was usually the season with the lowest nutrient export. Because of the effect of hydrology on seasonal nutrient exports, results from short-term studies conducted over two to three years need to be interpreted in the context of the seasonal rainfall distribution during the study, particularly in years affected by large, infrequent storms (e.g., hurricanes).

SECTION 1 - INTRODUCTION

Nonpoint sources of nutrients (NPS) are a widespread source of water pollution in coastal regions as well as inland drainage areas (U.S. EPA, 1992, 1993). In eastern North Carolina, nutrients washed into the estuaries of the Neuse and Tar-Pamlico rivers have caused excessive algal growth and episodes of poor water quality typically associated with nutrient over-enrichment (e.g., N.C. DEM, 1993, 1994). NPS inputs have been identified as the dominant contributors to total nutrient loadings in both basins (N.C. DWQ, 1998, 1999). To reduce nutrient loads—primarily nitrogen (N)—to the Pamlico and Neuse estuaries, the North Carolina Division of Water Quality (N.C. DWQ) has developed strategies for the Tar-Pamlico and Neuse river basins that include targets for dischargers and NPS contributions.

These management plans call for N reductions throughout the watershed to limit nutrient inputs in estuarine waters where algal blooms have occurred and bottom water dissolved oxygen (DO) has been depleted. Characterizing the sources of NPS nutrient loading to rivers is challenging due to variation in land use and management practices, physiographic setting, and site conditions such as soil type in addition to climatic variation that drives runoff. Further, management of nutrient inputs presents the added challenge of separating the influence of man's activities from natural processes that release nutrients from the watershed to aquatic systems. This "baseline" level of nutrient export is a key attribute of natural systems and is essential to maintain healthy and productive ecosystems.

Baseline nutrient exports vary by region and soil type due to variations in hydrology and biogeochemical processes affecting nutrient cycling among sites. For example, poorly drained soils typically export a larger fraction of annual rainfall as surface runoff than well-drained soils at upland sites due to high water table conditions that reduce infiltration (e.g., Skaggs et al., 1991). Differences in the route that water takes to the drainage outlet can affect nutrient concentrations and exports. Water that travels through the soil profile will transport soluble forms of nitrogen (N) and phosphorus (P), while surface flow may have a greater proportion in particulate forms. However, soluble forms of N and P may still predominate in surface outflow from low-gradient coastal plain forests in eastern North Carolina (e.g., Lebo and Herrmann, 1998).

The relative impact of land use on nutrient exports has received considerable attention in recent years as a means to better characterize NPS nutrient loading to aquatic systems (e.g., Howarth et al., 1996; Turner and Rabalais, 1991; U.S. EPA, 1994). Man's activities have been shown to affect both nutrient concentrations (Evans et al., 1995) and the total amount and timing of runoff from the land (Konyha et al., 1992; Skaggs et al., 1980). The effects on nutrient export of more invasive activities such as crop production and residential development have been fairly well documented and can be profound (Kronvang et al., 1995; Schueler, 1987). In comparative studies, nutrient exports from forestlands are typically much less than exports from more intensive land uses (e.g., Dodd et al., 1992). But no one has summarized or documented the effects of varying regional conditions on nutrient exports from forests or the effects of more subtle development such as managed forestry—an important commercial activity in North Carolina and throughout the Southeast—on these exports in the coastal plain of eastern North Carolina. Past work in the region has shown that nutrient exports from managed pine plantations in eastern North Carolina are often similar to the baseline nutrient exports from natural lands (Amatya et al., 1998). This similarity will usually occur for more than 90% of the timber growth cycle from shortly after establishment of the plantation until harvest. However, past studies on forest nutrient exports in eastern North Carolina have not comprehensively evaluated the variety of physiographic settings that occur on the coastal plain.

The purpose of this study was to assess baseline forest outflow characteristics in eastern North Carolina based on past and ongoing research studies. More than 100 site years of forest hydrology and water quality data from the past 25 years have been compiled, including sites with natural vegetation and sites managed for timber production. A total of 41 sites (watersheds) in Carteret, Craven, Jones, Tyrrell, and Washington counties were included, ranging in area from 7.3 to 6,070 ha. Some site years considered in this compilation were affected by harvest and aerial application of fertilizer. Harvesting has been shown to cause short-term increases in some nutrient fractions and total outflow, while fertilization can increase nutrient concentrations (e.g., Shepard, 1994). Therefore, site years affected by harvest or fertilization were excluded except for larger watersheds (of more than 200 ha) for which harvest or fertilization affected less than 10% of the watershed. The intent was to characterize the current baseline for forested sites located on flat divides between coastal streams and rivers in the coastal plain. Upland sites in more rolling topography and bottomland or riparian swamp forests also were excluded from the database.

The data summarized in this report are from field studies of varying lengths of time and with varying monitoring intensities. The studies can be broadly categorized into those that quantify both the outflow volume and nutrient concentrations and those that only quantify nutrient concentrations. Nutrient exports can be directly calculated from the first category of study. For the latter category of studies, reported nutrient concentrations provide comparisons with the more comprehensive studies and provide an opportunity to estimate long-term nutrient exports based on regional hydrology.

This report describes site characteristics and the experimental design for each of the 10 studies included. In evaluating nutrient exports from the forest sites, the report separates variation in outflow characteristics associated with hydrologic components, such as rainfall and hydrologic response, from nutrient concentrations that would vary with site characteristics. Outflow characteristics are summarized by season (e.g., winter quarter) and on an annual basis. The intent of the report is to characterize the range of forest nutrient exports observed in the coastal plain. Hydrological and nutrient concentration data from the study sites are used to examine how variation among sites may be related to soil type, drainage intensity, vegetation, and physiographic setting.

SECTION 2 - SITE DESCRIPTIONS

The hydrology and water quality results presented in this report came from nine research studies (referred to as full-year studies) and a broad survey of forested watersheds (referred to as the Weyerhaeuser multi-tract study) in diverse physiographic settings (Fig. 2.1). Forty-one individual blocks or watersheds ranging in area from 7.3 to 6,070 ha were included in this compilation. Table 2.1 provides a synopsis of site characteristics for all monitored locations included in this report, and Table 2.2 provides the general designs for the studies. Nutrient concentrations in the studies were analyzed by standard colorimetric methods (e.g., APHA, 1989).

Full-Year Studies

Carteret County - Carteret 7

Forest outflow characteristics of three paired 25 ha experimental watersheds at the Weyerhaeuser Carteret 7 Tract have been monitored since 1988 through cooperative research studies involving Weyerhaeuser, North Carolina State University, and the University of Georgia. The site is about 10 km north of Beaufort, N.C., with the experimental watersheds located at the south end of the tract (Fig. 2.1). Soils at the Carteret 7 site are deep, fine sandy loams of the Deloss series (fine-loamy, mixed, semiactive, thermic Typic Umbraquults) that overlay sandy marine terraces. Due to flat topography and low elevation (less than 3 m), a ditch system was installed in the early 1970s to improve drainage. Outflow from the experimental watersheds flows to the Core Creek Canal section of the Intracoastal Waterway via Eastman Creek. The managed loblolly pine (*Pinus taeda*) stands in the watersheds were established in 1974 and thinned in 1980 and 1988.

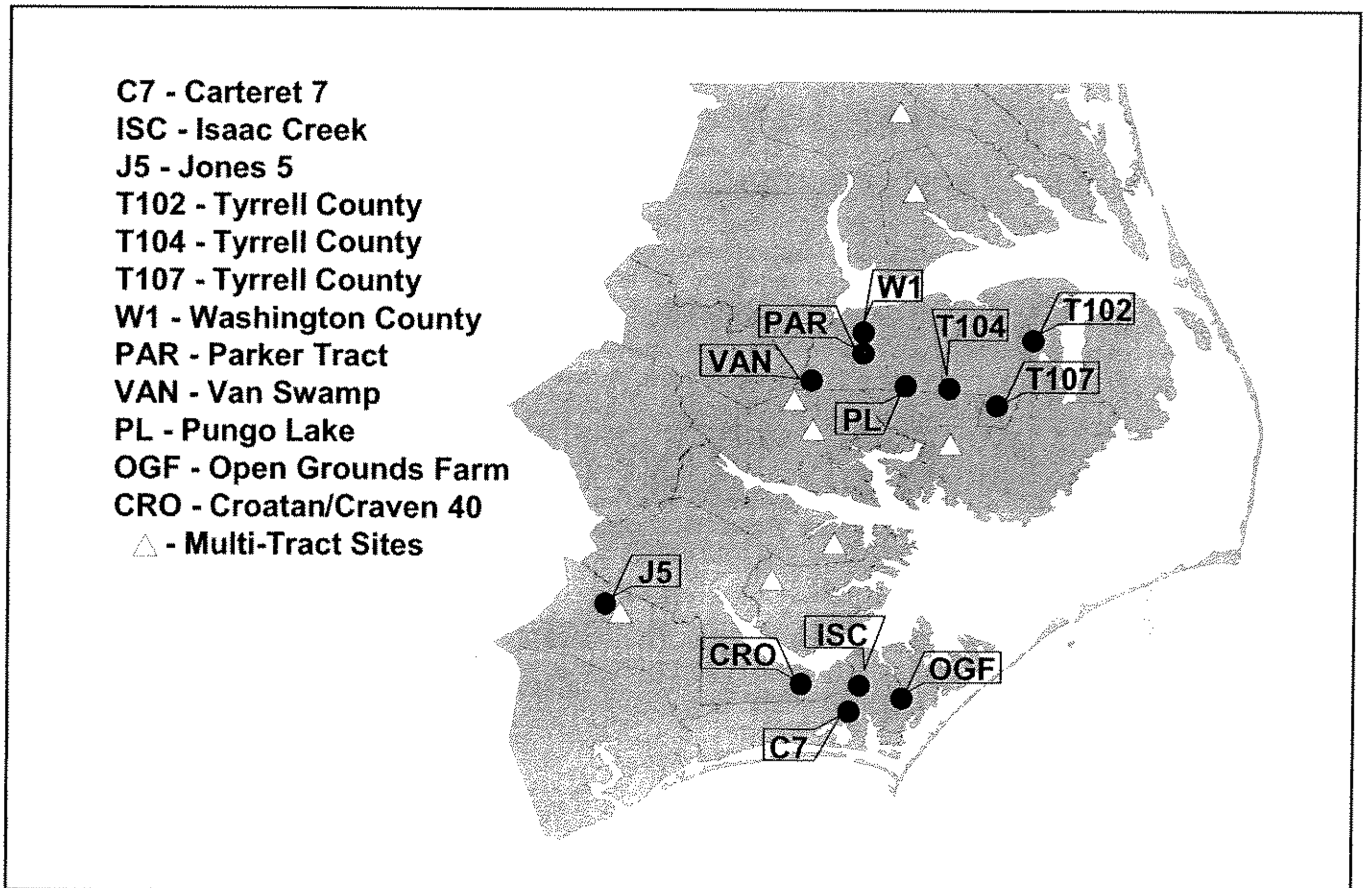


Figure 2.1. Map of eastern North Carolina showing the field study sites. The multi-tract study sites are identified in Figure 2.11.

Table 2.1. Site characteristics for monitoring locations included in this review.

Site	Block	Area (ha)	Soil Series	Drainage System (m) Field	Spacing	Depth	Vegetation
Carteret 7[1]	D1	25	Deloss sl	Yes	100	1.2-1.6	Managed loblolly pine
Carteret 7	D2	25	Deloss sl	Yes	100	1.2-1.6	Managed loblolly pine
Carteret 7	D3	25	Deloss sl	Yes	100	1.2-1.6	Managed loblolly pine
Isaac Creek[2]	B	91	Pungo, Dare m	Yes	100	1.0	Managed loblolly pine
Isaac Creek	D	109	Deloss, Arapahoe sl; Dare m	Yes	130-200	0.9	Mixed pine; natural pocosin
Isaac Creek	ABC	359	Ponzer, Dare, Pungo m; Deloss, Arapahoe sl; Argent l	Yes	100-200	~1.0	Mixed pine; natural pocosin
Isaac Creek	UD	83	Pungo, Dare m	No	N/A	N/A	Natural pocosin
Jones County[3]	J1	101	Torhunta, Grifton, Woodington sl	Yes	100	1.5	Managed loblolly pine
Jones County	J2	71	Torhunta, Grifton, Woodington sl	Yes	100	1.5	Managed loblolly pine
Jones County	J3	65	Torhunta, Grifton, Woodington sl	Yes	100	1.5	Managed loblolly pine
Tyrrell County[4]	T102	73	Weeksville sl	Yes	90	1.2-1.6	Natural forest
Tyrrell County	T104	129	Pungo m	No	N/A	N/A	Natural stunted pond pines and native shrubs
Tyrrell County	T107	73	Belhaven m	Yes	90	1.2-1.6	Pond pines; gallberry
Washington County[5]	W1	350	Portsmouth sl	No	N/A	N/A	Hardwood swamp forest; some pines
Parker Tract[6]	F1	18	Cape Fear sl	Yes	90	1.2-1.5	Managed loblolly pine
Parker Tract	F3	47	Cape Fear sl	Yes	80	1.2-1.5	Managed loblolly pine
Parker Tract	F4	99	Pungo m	Yes	100	1.2-1.5	Natural hardwood
Parker Tract	F5	127	Belhaven m	Yes	90	1.2-1.5	Managed loblolly pine
Parker Tract	F6	90	Belhaven m	Yes	90	1.2-1.5	Managed loblolly pine
Parker Tract	F7	160	Belhaven m	Yes	100	1.2-1.5	Natural hardwood
Parker Tract	F8	64	Cape Fear sl	Yes	100	1.2-1.5	Managed loblolly pine
Parker Tract	S4	2,900	Cape Fear, Portsmouth sl; Belhaven m	Yes	100	1.2-1.5	Natural hardwood; managed loblolly pine
Van Swamp[7]	VAN	6,070	Portsmouth, Arapahoe sl; Pungo, Belhaven m	Yes	Varies	unk	Natural forest; loblolly pine; 5% agriculture
Pungo Lake[7]	PL	75	Pungo m	No	N/A	N/A	Natural pond pines and wetland shrubs
Croatan/Craven 40	CR43	297	Pantego, Masontown, Rains, Tomotley sl	No	N/A	N/A	Natural forest
Croatan/Craven 40	HA1	407	Pantego, Masontown, Rains, Tomotley sl	19%	80-90	1.2-1.5	Natural pocosin; managed loblolly pine
Croatan/Craven 40	HA3	148	Pantego, Rains, Tomotley sl	Yes	80-90	1.2-1.5	Managed loblolly pine
Open Grounds[8]	OG1	630	Deloss, Tomotley sl; Ponzer m	Some	Varies	unk	Managed and natural pine; pocosin; hardwood

Legend: N/A = not applicable; unk = unknown.

Table 2.1. Site characteristics for monitoring locations included in this review (continued).

Site	*Block*	*Area (ha)*	*Soil Series*	*Drainage System (m)*			*Vegetation*
				Field	*Spacing*	*Depth*	
Open Grounds	OG8	259	Belhaven, Wasda m	No	N/A	N/A	Natural pocosin
Open Grounds	OG10	777	Roanoke, Deloss l; Ponzer, Wasda m	No	N/A	N/A	Natural forest
Morrison Tract	MOR	2,272	Pungo, Belhaven m; Icaria sl	Yes	100	~1.2	Managed loblolly pine; natural pocosin
Kramer Tract	KRA	807	Tomotley sl; Cape Fear, Roanoke, Portsmouth l	Yes	200	~1.2	Managed loblolly pine
Hyde 15 Tract	H15	496	Portsmouth l; Pettigrew m; Brookman cl	Yes	100	~1.2	Managed loblolly pine
Rodman-Meyer Tract	ROD	1,854	Croatan, Dare m; Torhunta sl; Bayboro l	Yes	100	~1.2	Managed loblolly pine; natural pine
J&W Tract	JW1	1,300	Bethera, Pantego l, Lynchburg, Rains sl	Yes	100-200	~1.2	Managed loblolly pine
J&W Tract	JW2	750	Bethera, Pantego l; Lynchburg, Rains sl	Yes	100-200	~1.2	Managed loblolly pine
J&W Tract	JW3	1,552	Bayboro, Pantego, Rains, Leaf l; Croatan m	Yes	100-200	~1.2	Managed loblolly pine
J&W Tract	JW4	371	Bayboro, Leaf l; Lynchburg sl	Yes	200	~1.2	Managed loblolly pine
Abbott Tract	ABB	580	Dare, Ponzer, Wasda m	Yes	200	~1.2	Managed loblolly pine, natural pocosin
Big Pocosin	BIG	819	Bayboro, Leaf l	Yes	100-200	~1.2	Managed loblolly pine
Bates Bay	BAT	1,050	Croatan m; Torhunta, Stockade, Woodington sl; Murville s	Yes	100-200	~1.2	Managed loblolly pine; natural hardwood

[1]Amatya et al. (1996, 1998), McCarthy et al. (1991).
[2]Amatya et al. (1997), Lebo and Herrmann (1998).
[3]Herrmann and White (1996), Fromm and Herrmann (1996).
[4]Skaggs et al. (1980).
[5]Chescheir et al. (1995).
[6]Chescheir et al. (1998).
[7]Daniel (1981).
[8]Kirby-Smith and Barber (1979).

Legend: N/A = not applicable; unk = unknown.

Table 2.2. Summary of study sampling designs.

Site	*Blocks*	*Periods*	*Rainfall*	*Flow*	*Nutrients*
Carteret 7[1]	D1; D2; D3	1988 - 95	Automatic onsite rain gauge	Continuous; V-notch weir	Composite & grab samples; automatic sampler
Isaac Creek[2]	B	1985 - 88 1991 - 94	Automatic onsite rain gauge	Continuous; V-notch weir	Biweekly grab samples
Isaac Creek[2]	ABC; D	1985 - 94	Automatic onsite rain gauge	Continuous; V-notch weir	Biweekly grab samples
Isaac Creek[2]	UD	1985 - 88 1995 - 96	Automatic onsite rain gauge	Continuous; V-notch weir	Biweekly grab samples
Jones County[3]	J1; J2; J3	1981 - 84	Manual onsite rain gauge; weekly	Continuous; V-notch weir	Automatic sampler and grab samples
Tyrrell County[4]	T102; T104; T107	1976 - 79	Automatic onsite rain gauge	Continuous; V-notch weir	Automatic sampler
Washington County[5]	W1	1993 - 96	Automatic onsite rain gauge	Continuous; flume	Automatic sampler
Parker Tract[6]	F1; F3; F4; F5; F6; F7; F8; S4	1996 - 98	Automatic onsite rain gauge	Continuous; V-notch weir	Automatic sampler and grab samples
Van Swamp[7]	VAN	1976 - 79	Rain gauge onsite	USGS gauge	Monthly
Pungo Lake[7]	PL	1976 - 79	Rain gauge onsite	USGS gauge	Monthly
Croatan/Craven 40	CR43; HA1; HA3	1995 - 96	None	None	Grab samples; 3-7 per quarter
Open Grounds Farm[8]	OG1; OG8; OG10	1975 - 76	None	None	Grab samples; biweekly
Weyerhaeuser Multi-Tract	11 Sites	1997 - 00	None	None	Grab samples; 3-4 per quarter

[1]Amatya et al. (1996, 1998), McCarthy et al. (1991).
[2]Amatya et al. (1997), Lebo and Herrmann (1998).
[3]Herrmann and White (1996), Fromm and Herrmann (1996).
[4]Skaggs et al. (1980).
[5]Chescheir et al. (1995).
[6]Chescheir et al. (1998).
[7]Daniel (1981).
[8]Kirby-Smith and Barber (1979).

Monitoring of outflow at the three paired watersheds began in 1988 just before the second thinning of the 14-year-old loblolly pine stands. Outflow from each stand was isolated from surrounding forest blocks by inserting plugs in the ditch system. In each stand, the drainage system consisted of four parallel field ditches, spaced 100 m apart, connected to isolate collector ditches at the west side of each block (Fig. 2.2; Amatya et al., 1998). Flash-board riser structures with 120° V-notch weirs were installed at the outlet of each stand. For a pre-treatment calibration period (1988 to 1990), all three watersheds were managed under a conventional drainage regime. Seasonal controlled drainage treatments (Amatya et al., 1998) were then applied to watersheds D2 and D3 while the third watershed (D1) remained in conventional drainage. For this treatment period (1990 to 1995), outlet weir settings for watersheds D2 and D3 were changed seasonally, at settings between 0.4 and 1.0 m below the soil surface, while the D1 weir was maintained at a depth of 1.0 m. Outflow data included in this summary report are for periods when the outlet weir setting for a given watershed was under the conventional drainage regime (e.g., depth = 1.0 m).

Water stage upstream of outlet V-notch weirs was recorded continuously throughout the study with Leupold-Stevens recorders equipped with electronic dataloggers. Rainfall was measured near each outlet with tipping bucket recorders and backup manual rain gauges. In addition to monitoring of outflow and rainfall, complete water balances for each stand were developed that included estimates of evaporation (soil and intercepted rain), transpiration, water storage in the soil column, and lateral seepage (see Amatya, 1993; McCarthy et al., 1991). Soils were characterized for water retention capacity and hydraulic conductivity.

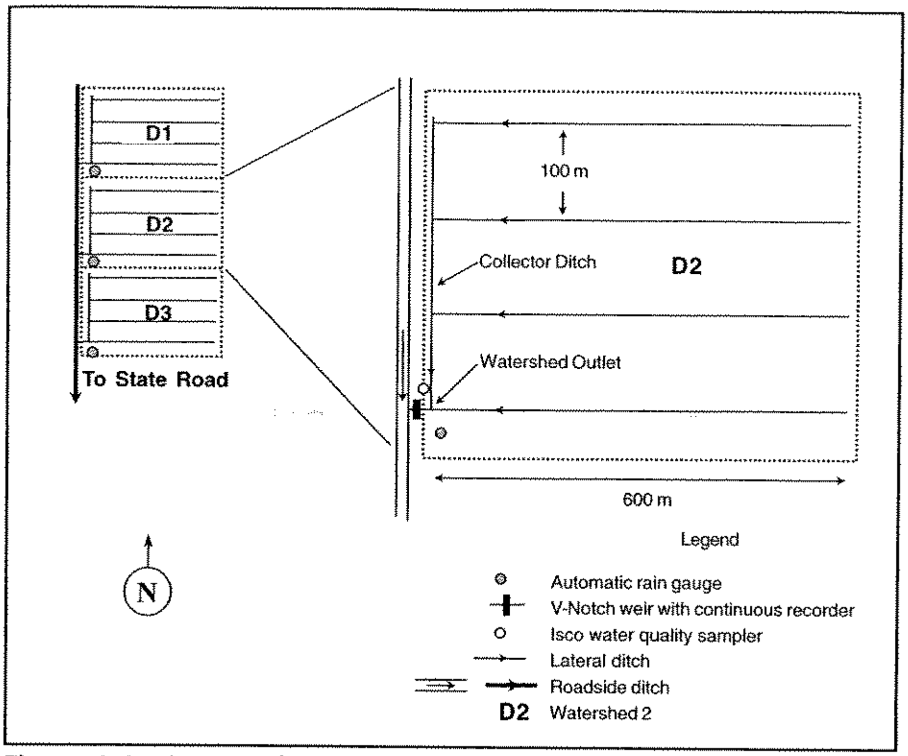


Figure 2.2. Site map for the Carteret 7 paired watersheds (after Amatya et al., 1998).

Water samples for the study were collected by automated Isco samplers and as grab samples approximately every week. Nutrient fractions analyzed in the study include NO_3-N, NH_4-N, TKN, and TP. Nutrient export was computed by multiplying concentrations from the composite samples by the outflow during each collection period. Values for the collection periods were summed to determine quarterly and annual exports. Water quality characteristics are based on the grab samples from July 1989 to February 1996, which are consistent with prior descriptions based on composites from automated sampling (Amatya et al., 1998; Smith, 1994).

Carteret County - Isaac Creek

Forest outflow was monitored at a second Weyerhaeuser site in Carteret County during 1985 to 1996 to assess how silvicultural operations affected outflow quantity and quality. The site is located near Beaufort (6.5 km north of the Carteret 7 site) and is bordered by the Intracoastal Waterway on the west and by Secondary Road 1300 and Open Ground Farms on the east (Fig. 2.1, Fig. 2.3). Both the Isaac Creek and Carteret 7 sites are part of a continuous forest tract (2,000 ha) under Weyerhaeuser management. Forestry operations conducted at the site over those years included road maintenance, ditch renovations and maintenance, timber harvest, site preparation, and replanting (Lebo and Herrmann, 1998). Throughout these activities, discharge and water quality characteristics were monitored on drainage from 550 ha of the larger Isaac Creek Tract.

The elevation of the site varies from a maximum of 3 m on the plateau of the interstream divide to less than 1.5 m at the outlet points to Isaac Creek (Fig. 2.3). Soils on the site include both organic mucks on the central plateau of the

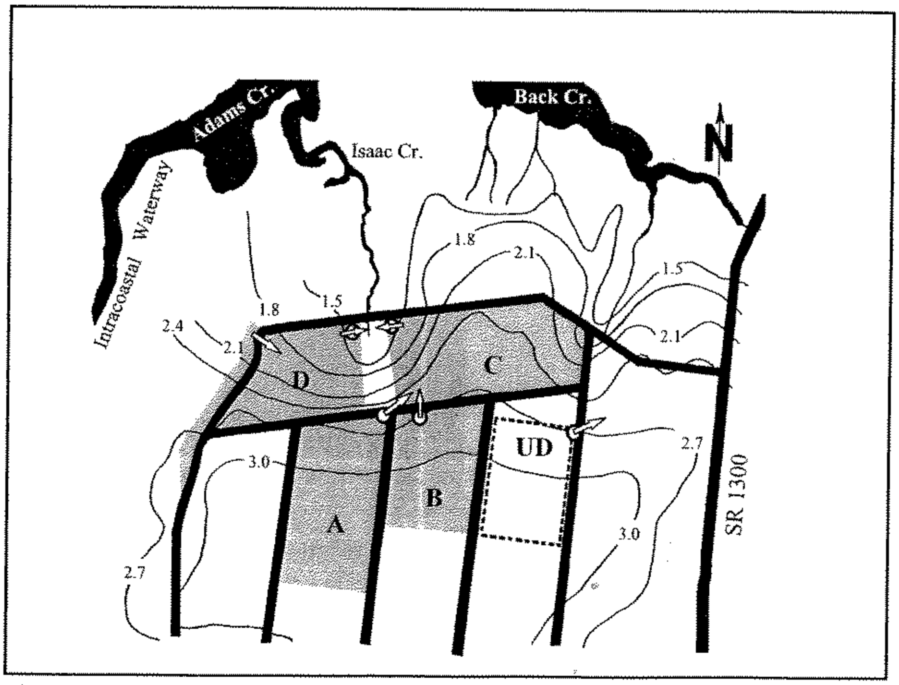


Figure 2.3. Isaac Creek watershed and adjacent Unditched (UD) block in relation to larger managed forest tract. Shaded region indicates boundaries of isolated forest stands, while thick lines denote the road system for the site. Approximate topography of the site in meters is shown with thin solid lines. Shaded circles show monitoring points, with arrows indicating outflow destination (adapted from Lebo and Herrmann, 1998).

interstream divide and heterogeneous organic and mineral soils near the outlets to Isaac Creek. Outflow leaves the overall tract through six outlets: two to the North River, two to the Intracoastal Waterway, one to Back Creek, and one to the headwaters of Isaac Creek. The focus of this study was to monitor the quantity and quality of outflow leaving the tract through Isaac Creek. Riser weirs and earthen plugs were installed to isolate approximately 550 ha of the tract, with drainage from two outlets (ABC and D) forming the headwaters for Isaac Creek (Fig. 2.3). Monitoring stations were located at the two watershed outlets and at the outlet of block B (a subwatershed of ABC). These three stations provided data on outflow and nutrient concentrations during ongoing forestry operations. In addition to these stations, a station was installed to monitor the outflow and nutrient concentrations from an adjacent unditched natural area (block UD). Following are details of the four monitored watersheds:

- **B**–Forest stands on this 91 ha watershed are entirely managed loblolly pine. The block was harvested and loblolly pine was replanted in stages from 1991 until 1993. Soils are Pungo muck (Dysic, thermic Typic Haplosaprists) and Dare muck (Dysic, thermic Typic Haplosaprists), deep organic soils of sapric origin, which overlay sandy marine terraces. The block is drained by 1 m deep ditches spaced 100 m apart.
- **D**–Forest stands on this 109 ha watershed are primarily managed loblolly pine at various stages of rotation, although there are isolated areas of natural pond pine stands (*Pinus serotina*). Soils are Deloss and Arapahoe (coarse-loamy, mixed, semiactive, nonacid, thermic Typic Humaquepts) sandy loams and Dare muck. The block is drained by 0.9 m deep ditches spaced 130 to 200 m apart.
- **ABC**–This 359 ha watershed consists of blocks A, B, and C. Primary forest stands are managed loblolly pine at various stages of rotation, although there are isolated areas of natural pond pine stands in block C. Soils are Pungo and Dare mucks in blocks A and B. Block C has Deloss and Arapahoe sandy loams, Argent loam (fine, mixed, active, thermic Typic Endoaqualfs), and Ponzer muck (loamy, mixed, dysic, thermic Terric Haplosaprists) in addition to Pungo and Dare mucks. Ditches are spaced 100 m apart (1 m deep) on blocks A and B and 130 to 200 m apart (0.9 m deep) on block C.
- **UD**–The forest stand on this 83 ha watershed is an unditched natural stand of pond pine. Soils are Pungo and Dare mucks.

Discharge at the four monitoring locations was measured using flashboard riser structures with 120° V-notch weirs (e.g., Skaggs et al., 1980). The weirs were calibrated in place, with discharge estimated from recorded stage on the upstream side of the weirs using Stevens type F (metric) water level recorders (Model 68). Data were also stored by data loggers (Omnidata DP115) and retrieved monthly. Weir heights were identical for the ABC and D outlets, but the settings for the other paired blocks differed considerably. The block UD weir was set near the soil surface to restrict flow in an attempt to mimic conditions in an undeveloped pond pine forest, while the block B weir was 0.9 m lower. This difference in weir heights and operational changes in weir settings associated with forestry operations affect data comparability among the four sites and across the different years of the study.

Rainfall at the site was monitored continuously from 1989 to 1995 with a Qualimetrics Tipping Bucket Rain Gauge equipped with a datalogger to record daily values. For earlier dates, rainfall was measured every week with a manual Taylor Rain Gauge (1986 to 1988), or regional precipitation data (for Cedar Island, Morehead City, and New Bern) were averaged (1985). Water quality samples for nutrient analyses were collected biweekly as grab samples. When there was no discharge over the weirs, samples were not processed even if water was present behind the structure. Water quality samples were collected throughout the study from the ABC and D outlets but only for a portion of the period from blocks B (1985 to 1988 and 1991 to 1994) and UD (1985 to 1988). Additional monitoring of the water quality for block UD was conducted in 1995 to 1996 concurrent with the Croatan/Craven 40 study.

Nutrient exports were determined by quarter for NH_4-N, NO_3-N, TN, PO_4-P, and TP by multiplying the flow-weighted average concentration for each fraction by total outflow. Flow-weighted quarterly averaged nutrient concentrations were used to derive exports due to the infrequent (biweekly) sampling schedule for nutrients compared with storm-related hydrographs. Due to impacts of timber harvest on water quality (Lebo and Herrmann, 1998), study years affected by harvesting/replanting within a large portion of the drainage area were omitted for that monitoring location: (block B) 1987, 1991 to 1993; (block D) 1989 to 1992; and (ABC outlet) 1986 to 1987, 1991 to 1992. Mean seasonal exports for the study period at each monitoring location were derived by averaging calculated exports for all years not affected by the several-year harvesting/replanting cycle. Average nutrient exports for block UD adjacent to the Isaac Creek watershed were estimated for the entire study period from average nutrient concentrations for 1986 to 1988 and 1995 to 1996 and from mean seasonal flows for the entire study period (i.e., 1986 to 1995).

Jones County

Forest outflow and nutrient concentrations were monitored during 1981 to 1984 at three adjacent stands of managed loblolly pine in the Weyerhaeuser Jones 5 Tract (Fig. 2.1). The site is approximately 32 km west of New Bern near Cove City, N.C. The Weyerhaeuser Company established this forest in the 1960s and has bought more land there over the past three decades. Most of the forest, currently 69 km^2, occupies an interbasin mineral flat (elevation 18 m) known as the Great Dover Swamp. Outflow from the forest enters Core Creek to the north (Neuse River) and Beaver Creek to the south (Trent River).

The three forested research stands are located near the center of Jones 5 (Fig. 2.4) on fine, sandy loam soils of the Torhunta, Grifton, and Woodington series. The soil horizon down to about 0.75 m is black loamy sand, which overlays either decomposed marl–Grifton series (fine-loamy, siliceous, semiactive, thermic Typic Endoaqualfs)–or sandy, clay-loams–Torhunta series (coarse-loamy, siliceous, active, acid, thermic Typic Humaquepts) and Woodington series (coarse-loamy, siliceous, semiactive, thermic Typic Paleaquults). Drainage systems in the stands consist of parallel field ditches, spaced 100 m apart, that drain into larger roadside ditches. The elevation change across the stands is slight, about 0.6 m. Flashboard riser weirs were installed at these outlets in February 1981.

Following are descriptions of the three study blocks:

- J1–Most of this 101 ha block was planted with loblolly pine in 1978. The remaining 22 ha of the block is a stand of older loblolly pine, aerially seeded in 1964. The block was only monitored in 1981 and 1982; a portion of the block was cleared for a power line right-of-way in 1983, and sampling was discontinued then.

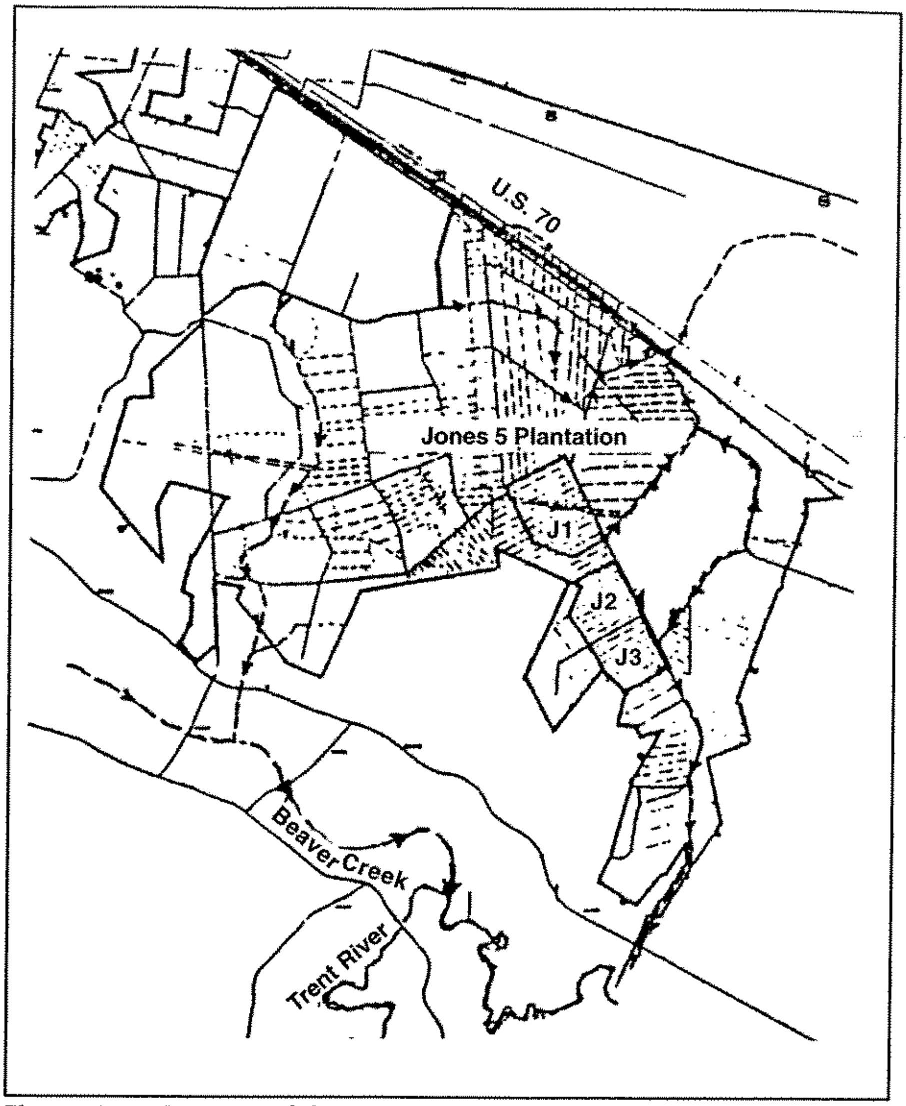


Figure 2.4. Site map of the Jones 5 paired watersheds showing the surface water drainage system.

- J2–This entire 71 ha block was planted with loblolly pine in 1978. The block was monitored from 1981 to 1984.

- J3–This entire 65 ha block was planted with loblolly pine in 1978. The block was monitored from 1981 to 1984. It was aerially fertilized with nitrogen and phosphorus in February 1983. This review excludes J3 nutrient export data for February through June 1983 when nutrient export was affected by the aerial fertilization (Herrmann and White, 1996).

Outflow was monitored continuously using stage recorders upstream of outlet weirs, with daily averaged flows determined from chart records. Rainfall was measured weekly with manual Taylor rain gauges located near each tract outlet. From February 1981 to December 1984, water samples were collected every week (grabs) or over several days using automated Isco samplers during storm events or following fertilization of the J3 block. Isco sample bottles for nutrient testing were spiked with HgCl to inhibit nutrient transformations during storage. Nutrient fractions analyzed include

TKN and soluble Kjeldahl N (SKN), NH_4-N, NO_3-N, TP, and total dissolved P (TDP). In 1983 and 1984, rainfall samples were also analyzed for N and P fractions.

Quarterly flow-weighted nutrient concentrations were calculated (rather than using simple means) to account for the collection of both grab and composite samples during the study. Nutrient exports were calculated by quarter over the entire study as the product of total flow for each quarter and the flow-weighted concentration. Annual exports were calculated by adding all quarterly values for a given year. The average annual export was calculated by adding average values for each season (e.g., winter values from 1981 to 1984).

Tyrrell County

Skaggs et al. (1980) examined the impact of land development for agricultural use on outflow characteristics and nutrient exports by studying three typical soil types in Tyrrell County. For each soil type, an undeveloped control site of similar drainage area (e.g., one with a natural woodland or forest canopy) was matched with a site being developed for agriculture; all were on the property of First Colony Farms. All sites were on flat, low-elevation lands (2 to 4 m) with surface slopes of less than 0.02%. Locations of the three sites are shown separately on the general map of the area in Figure 2.1, and the configurations of the sites are shown in Figure 2.5. The three pairs of sites were chosen to represent the three edaphic soil groups that span the full range of soils that can be used for agriculture in the region. Only the results from the undeveloped sites are presented in this review.

Following are descriptions of the experimental sites representing the three major edaphic groups:

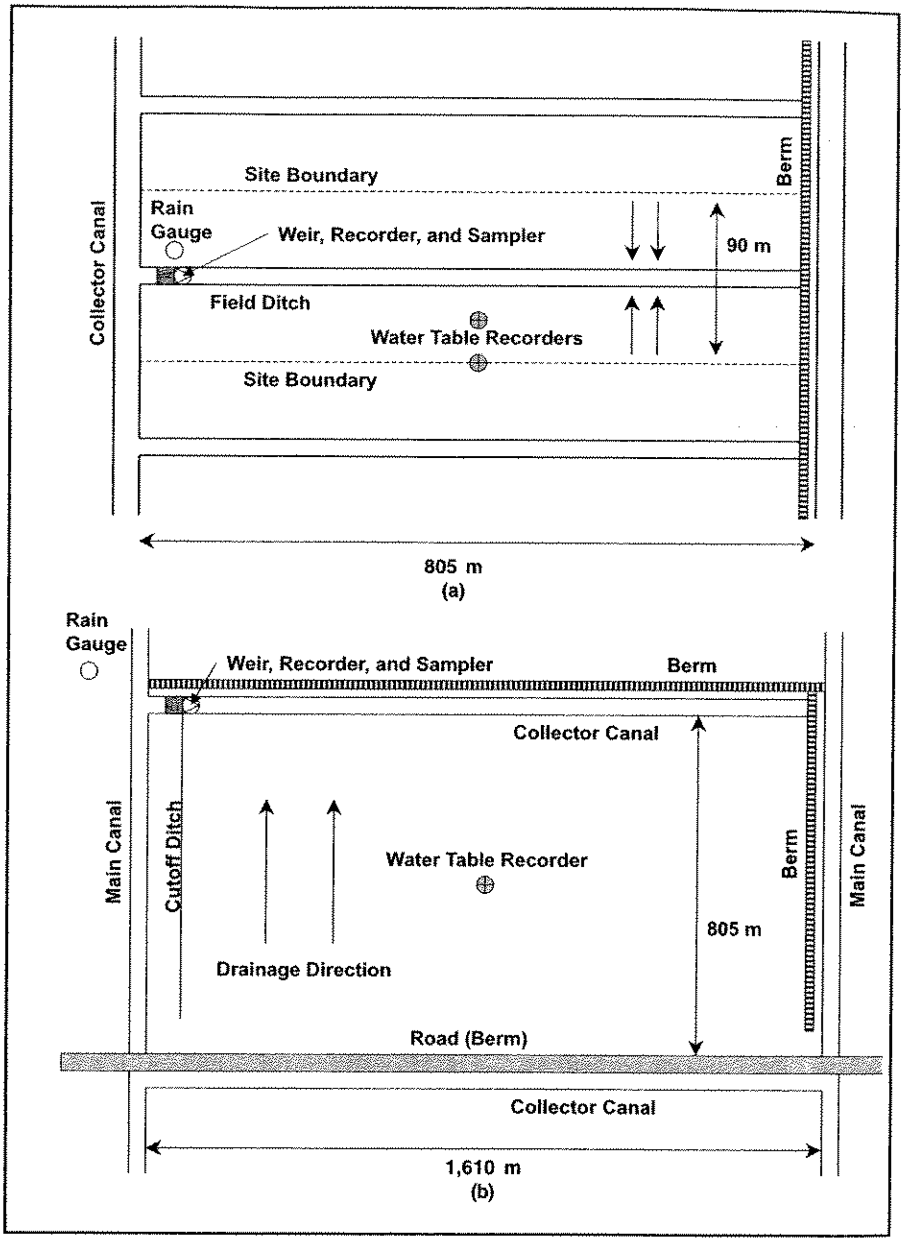


Figure 2.5. Site maps of study sites in Tyrrell County. Sites T102 and T107 were configured as shown in (a). Site T104 was configured as shown in (b).

- **T102**–The paired sites (T101 developed and T102 undeveloped) for the mineral soil group were located in Tyrrell County about 6 miles west of the Alligator River. The land is about 1.8 m above sea level. The Weeksville series (coarse-silty, mixed, semiactive, acid, thermic Typic Humaquepts) is a coarse, silty mineral soil with a histic epipedon. This group of soils is characterized by a surface horizon with a high organic matter content that does not extend deeply enough in the soil profile (less than 0.40 m) for the soils to be classified as organic. Site T102 had a stand of harvestable pine during the study. The site represented a natural forest drained by 1.2 to 1.6 m deep ditches spaced 90 m apart. Field measurements were collected from a single field ditch draining a 7.4 ha area.

- **T104**–The paired sites (T103 developed and T104 undeveloped) for the deep colloidal organic soil group were located in Washington and Tyrrell counties just south of Lake Phelps. These sites had elevations of 3.6 to 4.0 m, and the soil was in the Pungo series. This group of soils has colloidal organic matter horizons extending 1.3 m deep into the soil profile. The undeveloped site (T104) had a cover of stunted pond pine and native shrubs. The site had a drainage area of 129 ha, with runoff flowing into a collector canal. Field measurements were made from the collector canal. There were no field ditches in the undeveloped site.
- **T107**–The paired sites (T106 developed and T107 undeveloped) for the shallow organic soil group were located in Tyrrell County 4 miles east of New Lake. The low land elevation of the sites (0.9 to 1.5 m) is marginal for gravity drainage flow. The soils were in the Belhaven series (loamy, mixed, dysic, thermic Terric Haplosaprists) and had about 0.6 m of organic matter over a sandy loam subsoil. The amount of buried wood was relatively small. These soils typically have a high organic matter horizon that extends to depths of 0.4 to 1.3 m below the surface before contacting a mineral layer. The site represented a natural forest drained by 1.2 to 1.6 m deep ditches spaced 90 m apart. Field measurements were made from a single field ditch draining a 7.4 ha area. The undeveloped site had a cover of native pond pines and shrubs.

Skaggs et al. (1980) provides detailed descriptions of the soil profile at each location down to a depth of 12 m, which are not reproduced here.

Flashboard riser structures with weirs were installed at the outlet of each experimental block. The sharp-crested V-notch weirs were calibrated in place, and water level recorders continuously measured stage upstream of the weir to derive outflow rates. The weirs were submerged during some periods of high rainfall when water backed up in the outlet drainage canal. Methods for correcting the flow volumes for the submerged conditions are reported in Skaggs et al. (1980). Recording rain gauges were located at each site.

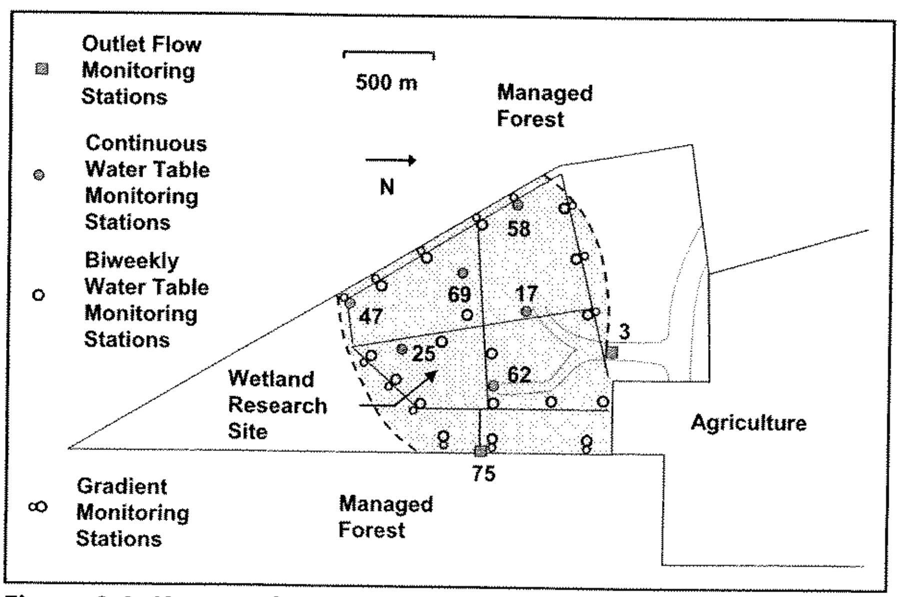


Figure 2.6. Site map for the Washington County wetland site showing surrounding land uses and locations of monitoring stations.

Automatic composite water samplers were located at the outlet of each site, and the composite samples were collected weekly for laboratory analyses. The composite samples were analyzed for TP, TKN, NO_3-N, and NH_4-N. Nutrient export was calculated by multiplying the weekly composite concentration value by the flow volume for the week.

Washington County

Chescheir et al. (1995) studied a natural forested wetland located on the Tidewater Research Station near Plymouth, N.C. (Fig. 2.1). The research site was on one of the few remaining undrained nonriverine swamp forests in North Carolina. The 350 ha wetland had not been logged or otherwise disturbed for over 40 years. It was essentially flat with a total variation in surface elevation of only about 0.5 m. The predominant soil type was a Portsmouth sandy loam (fine-loamy over sandy or sandy-skeletal, mixed, semiactive, thermic Typic Umbraquults), with smaller areas of Belhaven muck, Roanoke silt loam (fine, mixed, semiactive, thermic Typic Endoaquults), and Muckalee loam (coarse-loamy, siliceous, nonacid, thermic Typic Fluvaquents). The wetland was populated by swamp forest hardwood species including swamp tupelo (*Nyssa biflora*), bald cypress (*Taxodium disticum*), tulip tree (*Liriodendron tulipifera*), and red maple (*Acer rubrum*), and some loblolly pine. The wetland is bounded by agricultural land to the north and by managed forest (Parker Tract) to the west, south, and east (Fig. 2.6).

A portion of the wetland was selected as a site for intensive study from May 1993 through September 1996. This drainage area was approximately 137 ha and was delineated by ridges on the north and south and by managed forest on the east and west. Drainage from the watershed occurred through shallow, intermittent streams (less than 0.3 m deep) that combined to form a well-defined primary outlet on the northern end of the site. A shallow abandoned canal (less than 0.45 m deep) bordered the site on the east, forming a secondary outlet primarily as seepage. Overland flow during large runoff events may also have reached the canal.

The primary outlet was equipped with wing walls and a trapezoidal flume to measure the flow of surface water from the site. Stage was measured continuously in the trapezoidal section and 25 m upstream of the section. Water velocity and stage in the section were manually measured weekly, and these weekly measurements were used to develop a stage discharge relationship for the section. Flow from the secondary outlet was measured by a sharp-crested V-notch weir. Fifteen series of two or three wells were installed in lines perpendicular to the wetland perimeter to determine shallow groundwater gradients. These gradients were used for calculating subsurface inflow to or outflow from the watershed. A weather station that measured precipitation, air temperature, net radiation, relative humidity, wind speed, and wind direction was located 1.5 km north of the center of the wetland site. Three other recording rain gauges were located 3.1 km east, 3.0 km south, and 4.2 km west of the wetland center.

Automatic water samplers were installed at the outlets to collect samples for water quality analyses. The samplers were programmed to sample every day. The samplers were serviced every two weeks, at which time the samples were composited according to flow. During high-flow events, each daily sample was analyzed. Two days of samples were combined and analyzed for medium-flow periods, and three days of samples were combined and analyzed for low-flow periods. Nutrient export was calculated by multiplying the concentration values by the flow volume for the period represented by each composited sample.

Parker Tract

Weyerhaeuser's Parker Tract encompasses 4,000 ha of forested land located in Washington County approximately 11 km southeast of Plymouth, N.C. (Fig. 2.1). Forest outflow and nutrient concentrations have been monitored there since 1996 at the outlets of seven forest stands (18 to 160 ha) and at the outlet of a watershed draining 2,900 ha of managed and natural hardwood stands (Fig. 2.7). The monitoring was part of a larger study monitoring hydrology and water quality through the 10,000 ha watershed that includes the Parker Tract and the Washington County wetland site. The larger watershed includes other agricultural and forestland uses (see Chescheir et al., 1998). The overall objective of the large watershed study was to determine the cumulative effects of land use and management practices on nutrient loading at the outlet of a large coastal plain watershed.

Outflow from the Parker Tract enters Kendricks Creek 16 km upstream of the Albemarle Sound through three main outlets. Both mineral and organic soils are present on the watershed. The mineral soils are very poorly drained Portsmouth and Cape Fear series, while the organic soils are primarily Belhaven and Pungo series located in the southern part of the tract. The drainage system at the site is a network of field ditches and canals that divide the tract into a mosaic of regularly shaped fields and blocks of fields. Field ditches, which provide both surface and subsurface drainage, are spaced 80 to 100 m apart and range in depth from 0.6 to 1.2 m.

Following are descriptions of the monitoring locations:

- **F1**–This 18 ha block was planted with loblolly pine in 1992. Its soil is mineral soil of the Cape Fear series (fine, mixed, semiactive, thermic Typic Umbraquults). Ditches are 90 m apart.
- **F3**–This 47 ha block was planted with loblolly pine in 1983. Its soil is mineral soil of the Cape Fear series. Ditches are 80 m apart.
- **F4**–This 99 ha block is a mixed hardwood and pine stand (nonriverine swamp forest) that has not been harvested since 1920. Its soil is organic soil of the Pungo series. Ditches are 100 m apart. A deep drainage canal was adjacent to the site, and this situation resulted in significant lateral seepage from the block to the canal.
- **F5**–This 127 ha block was planted with loblolly pine in 1984. Its soil is organic soil of the Belhaven series. Ditches are 90 m apart. The site was near a deep drainage canal that caused significant lateral seepage from the block to the canal.
- **F6**–This 90 ha block was planted with loblolly pine in 1992. Its soil is organic soil of the Belhaven series. Ditches are 90 m apart.
- **F7**–This 160 ha block is a mixed hardwood and pine stand (nonriverine swamp forest) that has not been harvested since the 1920s and 1930s. The soil on the site is organic soil of the Belhaven series. Ditches are 100 m apart. The site was near a deep drainage canal that caused significant lateral seepage from the block to the canal.
- **F8**–This 64 ha block was planted with loblolly pine in 1979. Timber on the site was harvested in the summer of 1997 and is being used in a study of the effects of harvesting, site preparation, and regeneration on soil hydraulic properties and water quality. The data presented in this report only represent the time period before harvest. The soil on the site is mineral soil of the Cape Fear series. Ditches are spaced 100 m apart.

- **S4**–The outlet of this 2,900 ha watershed drains blocks of mixed hardwood and pine forests (nonriverine swamp forest) and blocks of managed loblolly pine plantation. Approximately one-third of the watershed is natural forest. Mineral soils make up approximately one-third of the watershed.

Water stage upstream and downstream of outlet V-notch weirs in riser structures was recorded continuously throughout the study with Leupold-Stevens recorders equipped with electronic dataloggers. Rainfall was measured at six locations in and around the Parker Tract with tipping bucket recorders and manual rain gauges as backups. Chescheir et al. (1998) provides additional information on instrumentation at the site and overall study objectives.

Water samples for the study were collected by automated samplers and as grab samples about every two weeks. Automatic samplers usually operated in a flow-proportioned composite mode during the study, except during special storm event samplings. Nutrient fractions analyzed in the study include NO_3-N, NH_4-N, TKN, and TP. Nutrient export was computed by multiplying concentrations from the composite samples by the outflow during each collection period. Values for the collection periods were added to determine quarterly and annual exports.

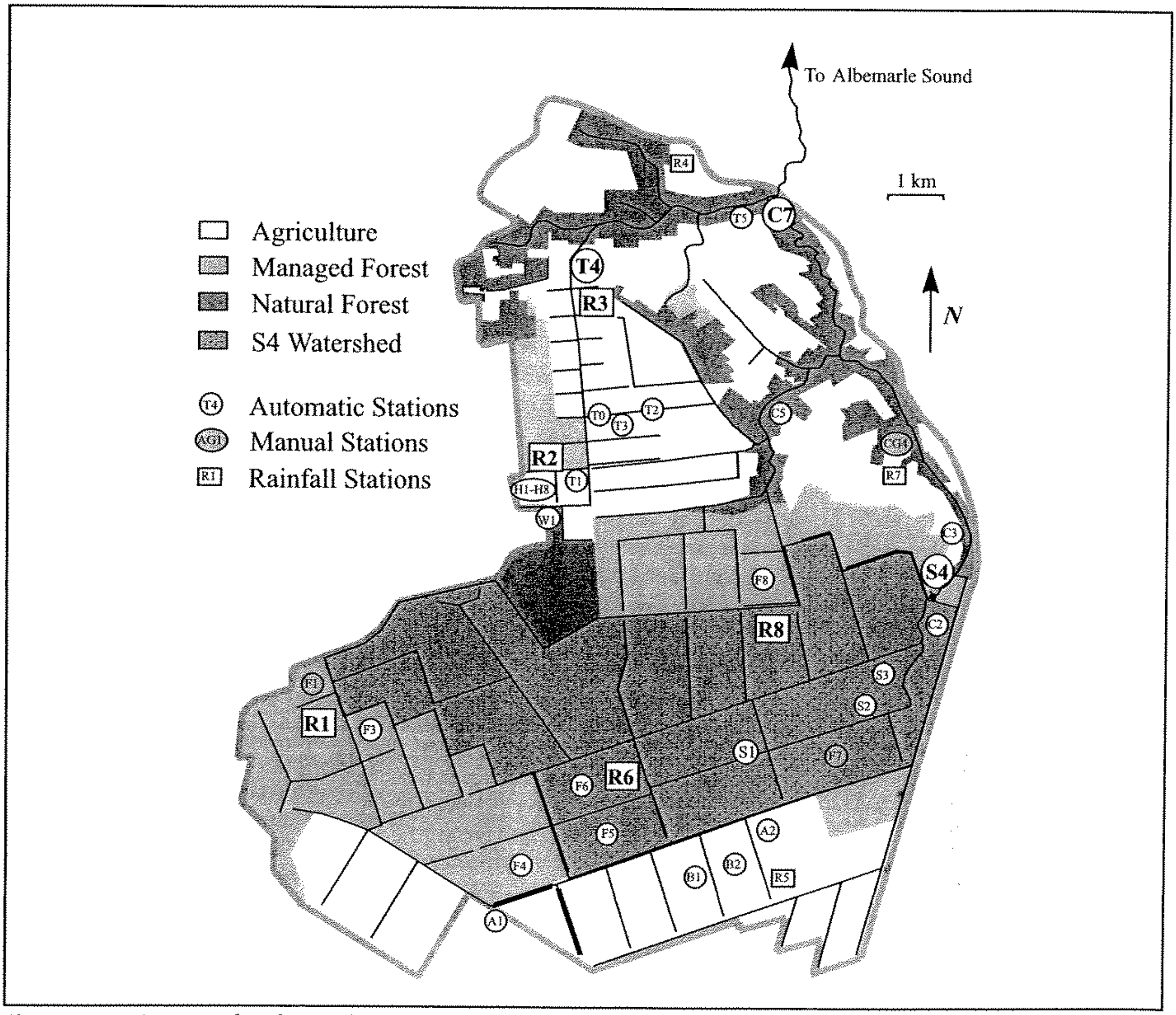


Figure 2.7. Site map for the Parker Tract within the 10,000 ha watershed instrumented to measure the effect of land use and best management practices on watershed hydrology and nutrient loading.

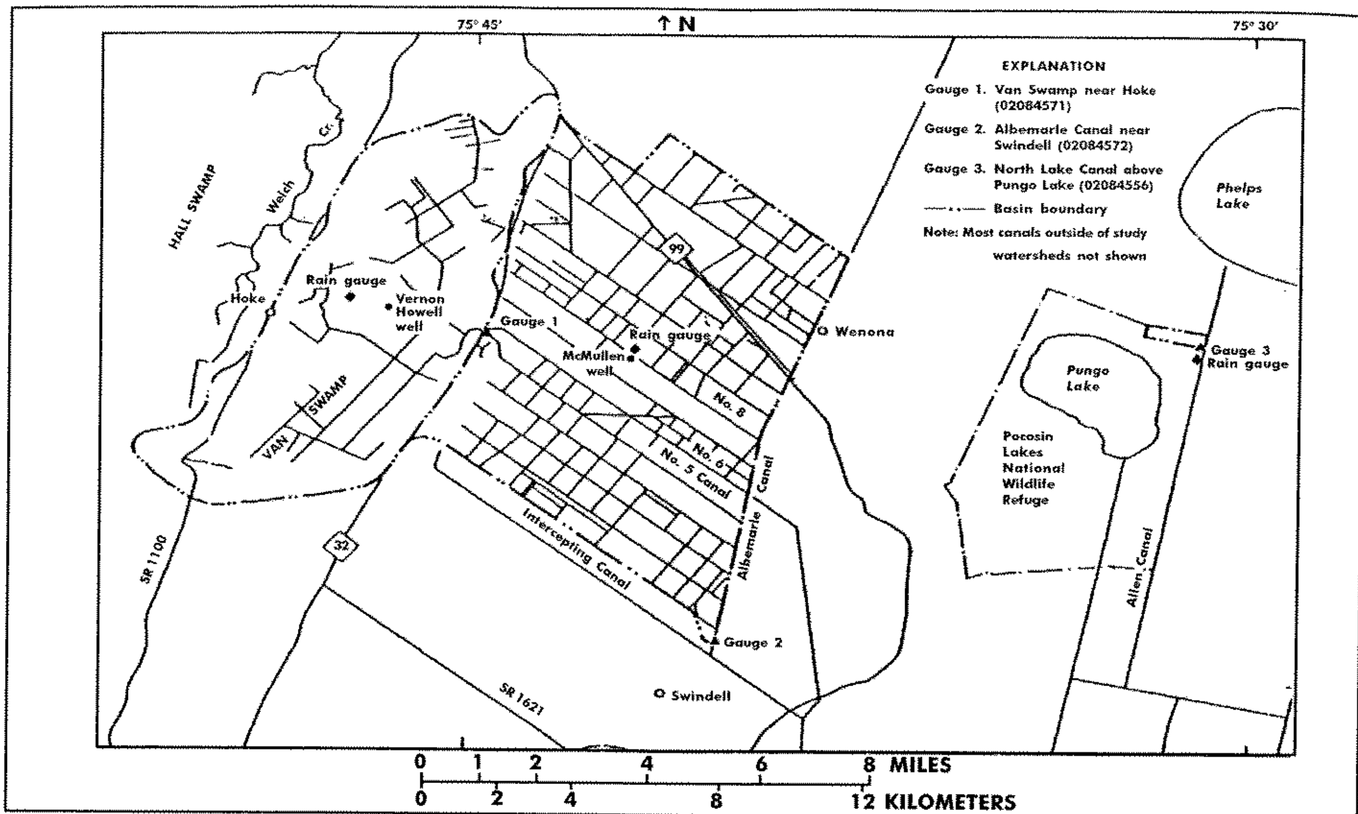


Figure 2.8. Site map for the Van Swamp and Pungo Lake study sites. The Van Swamp watershed was monitored at Gauge 1, and the Pungo Lake watershed was monitored at Gauge 3 (after Daniel, 1981).

Van Swamp and Pungo Lake

The U.S. Geological Survey initiated a study in 1976 to compare the flows and water quality of runoff from three sites near Plymouth N.C. (Daniel, 1981). One site, the Albemarle Canal watershed (116 km^2), had been developed for agriculture with an extensive drainage system (Fig. 2.8). The other two sites were Van Swamp, a relatively undeveloped mineral flat wetland forest, and a small organic flat with low pocosin vegetation on the Pungo Lake Wildlife Refuge (now Pocosin Lakes National Wildlife Refuge—PLNWR). Following are descriptions of the two forested sites (Van Swamp and Pungo Lake):

- **Van Swamp**–This 6,070 ha watershed is an elongate interbasin mineral flat (ca 4.8 x 12.8 km) that lies between a low sand ridge on the east (e.g., N.C. 32) and the Suffolk Scarp (e.g., Secondary Road 1100) on the west. Elevations approach 15 m along the scarp, and the watershed slopes gradually (0.01%) to the east to an elevation of 7.5 m at the outlet. Approximately 95% of Van Swamp was forested (about 50% managed loblolly pine plantation and 50% natural forest), and the remaining 5% was agriculture. About two-thirds of the natural forest was nonriverine wet hardwood forest, and the remaining one-third was pond pine woodlands. Soils in the northern two-thirds of the watershed are mineral sandy loams, predominantly in the Portsmouth and Arapahoe series. In the southern third of the watershed, the soils are predominantly organic in the Belhaven and Pungo series. Drainage outflow was gauged at a culvert under N.C. 32 where the outflow joined the Albemarle Canal watershed (see Fig. 2.8).
- **Pungo Lake**–This 75 ha organic flat block is located on the north boundary of the Pocosin Lakes National Wildlife Refuge and has low elevation (2.5 m). Vegetation on the block is pond pine (*P. serotina*), loblolly bay (*Gordonia lasianthus*), and various species of ericaceous shrubs. Soils are very deep, poorly drained peat of the Pungo series. Outflow from the site was isolated from surface runoff from adjacent farmland by spoil banks on the north boundary. On the south and west boundaries, ditches inside the spoil banks collected the outflow. Outflow was gauged at the southeast corner of the site where drainage entered Allen Canal and flowed south into the Pungo River headwaters.

Flow monitoring at the Van Swamp watershed (USGS 02084571) began in May 1977 and has continued until the present. Flow monitoring at the Pungo Lake site (USGS 02084556) began in May 1976 and ended in September 1979. Water quality samples were collected manually from both sites at approximately monthly intervals. Sampling at Pungo Lake began in June 1976 and ended in November 1979. Water sampling occurred during three periods at Van Swamp: March 1978 to November 1979; October 1984 to September 1987; and October 1993 to September 1995. Samples were analyzed for NO_3-N, TKN, SKN, TP, and TDP during the 1970s study. For the 1980s and 1990s study periods, samples were also analyzed for NH_4-N and PO_4-P, in addition to the other analyses. Seasonal nutrient export was calculated for each study period by multiplying the seasonal average concentrations by the corresponding average drainage volume for that period.

Croatan/Craven 40

The quality of runoff from the Croatan National Forest and adjacent managed forests (Craven 40) near Havelock, N.C. was monitored from October 1995 to September 1996. The goal was to collect data on background nutrient levels in the runoff from minimally disturbed forestlands with mainly mineral soils (Fig. 2.9). Water samples were collected to provide data on seasonal variations in nutrient concentrations from wetland forests on several mineral soil types. The sampling sites were near Havelock, within the Croatan National Forest along Bill Finger Road and in the Weyerhaeuser Craven 40 Forest Tract; initially (fall 1995), eight streams were surveyed in these sites.

Seven surveys for runoff water quality were conducted during October to December 1995. Based on the results from these surveys of a number of creeks draining similar soils, three "core" sites were selected to monitor for seasonal variations in nutrient concentrations during January to September 1996. These were:

- **CR-43**–This 297 ha area drains from mineral soil in the Croatan National Forest off Bill Finger Road at Pole 43. Upland soils in the watershed are black, fine sandy loams in the Pantego (fine-loamy, siliceous, semiactive, thermic Umbric Paleaquults), Rains (fine-loamy, siliceous, semiactive, thermic Typic Paleaquults), and Tomotley (fine-loamy, mixed, semiactive, thermic Typic Endoaquults) series. Mucky sandy loam soils of the Masontown series (coarse-loamy, siliceous, active, nonacid, thermic Cumulic Humaquepts) occur along natural drains.
- **HA-1**–This 407 ha area drains from ditched (80 to 90 m spacing) loblolly pine on mineral soil (e.g., HA-3 soils) in the Craven 40 Tract mixed with loamy mineral soils with a mucky surface component along the drain Masontown series. Outflow from a headwater pocosin area with Croatan series muck (loamy, siliceous, dysic, thermic Terric Haplosaprists) may also affect water quality.
- **HA-3**–This 148 ha area drains from ditched (80 to 90 m spacing) loblolly pine on fine sandy loams—Pantego, Rains, and Tomotley series in the Craven 40 Tract.

Water samples were collected from these three sites three to seven times per quarter and were analyzed for TKN, NH_4-N, NO_3-N, and TP. Basic water parameters (temperature, pH, conductivity, and dissolved oxygen) were measured with a YSI Model 3800 multimeter. Flow at the time of sampling was estimated where possible.

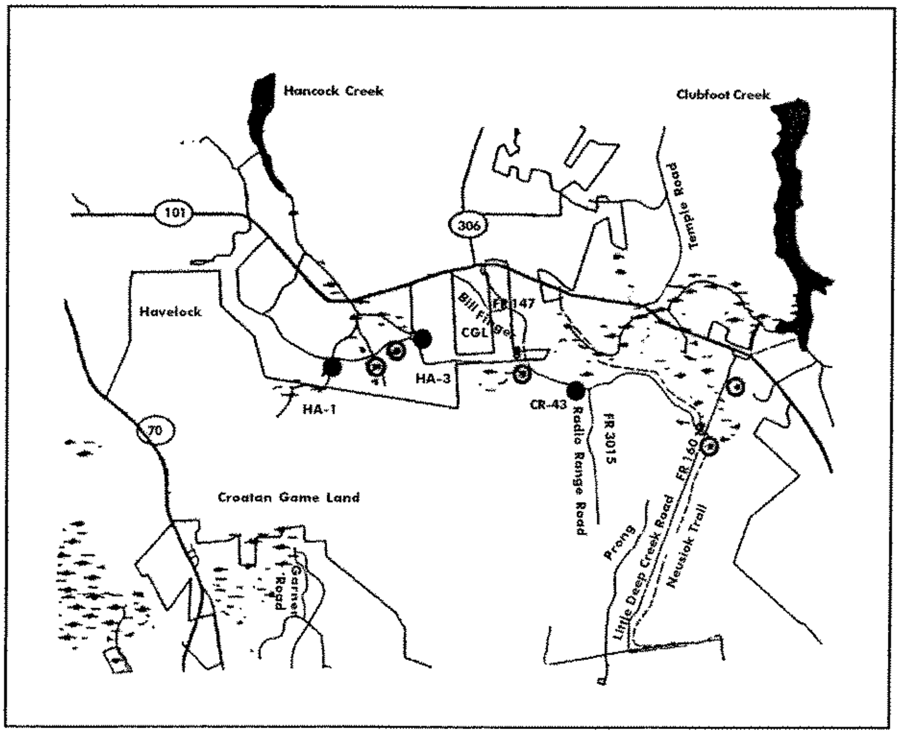


Figure 2.9. Site map for the Croatan/Craven 40 study sites. Closed circles indicate "core" sampling locations, while shaded circles indicate additional sampling locations during the synopic surveys.

Carteret County - Open Grounds Farm

The water quality of forest outflow in the Open Grounds region of Carteret County was monitored from 1975 to 1976 during the conversion of the site to intensive agricultural use (Kirby-Smith and Barber, 1979). The Open Grounds region is a large, low-elevation wetland about 16 km northwest of Beaufort. It is bounded by the Neuse River on the north and by Core Sound on the south and east. In January 1974, an agricultural corporation acquired 18,200 ha to develop Open Grounds Farm (OGF). It constructed drainage ditch systems, cleared land, and established grassed pasture areas and row crops (corn and soybeans). The natural vegetation had included pond pine woodlands, pocosin ericaceus wetland shrubs and trees, and open grasslands. Drainage from OGF flows into South River, Back Creek, and North River (Fig. 2.10).

Study sites pertinent to this review include two sites within OGF (a pocosin and a natural forest) and one site for monitoring outflow from predominantly forested areas adjacent to OGF. Following are the OGF and nearby forest area stations whose data were included:

- **OG 1**–A roadside ditch along Merrimon Road received outflow from the 630 ha Cozier Tract of International Paper (now managed by Weyerhaeuser Company). The drainage area included managed and natural pine stands (*P. taeda, P. serotina*). Soils are Deloss and Tomotley sandy loams in the hardwood and pine stands and Ponzer muck in the pocosin area.
- **OG 8**–This 259 ha undeveloped organic flat was located in the center of OGF. Drainage flowed to South River. Soils on the pocosin are Belhaven and Wasda (fine-loamy, mixed, semiactive, acid, thermic Histic Humaquepts), poorly drained mucks overlaying sandy marine terraces.
- **OG 10**–A natural forest stream eventually draining to North River received runoff from this site. The site was sampled more routinely in 1976 than in 1975. Soils in this 777 ha creek watershed are poorly drained loams (Deloss and Roanoke) and Wasda and Ponzer mucks, which overlay sandy marine terraces.

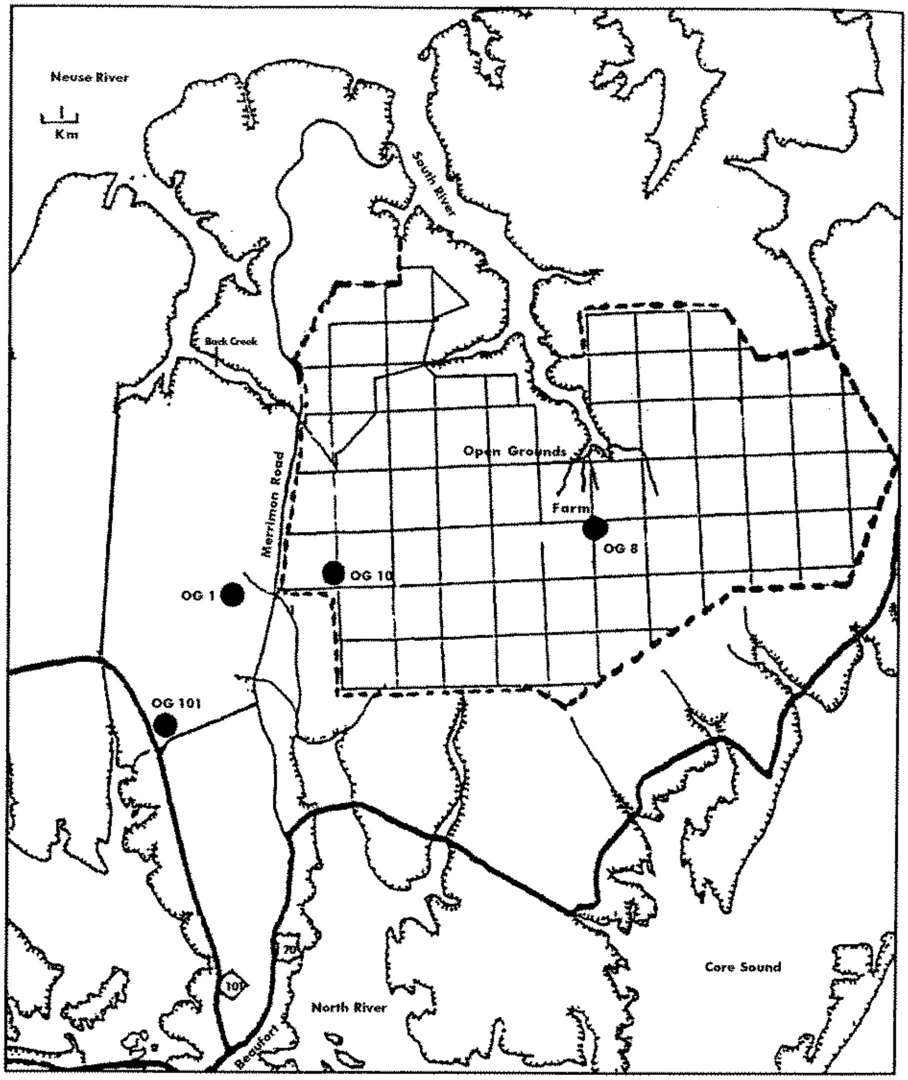


Figure 2.10. Site map of the Open Grounds Farm study sites in Carteret County (after Kirby-Smith and Barber, 1979).

In the Duke University Marine Lab (DUML) sampling program at these sites, grab water samples were taken two or three times a month throughout the year at 11 sites in 1975 and at six in 1976. Outflow volumes or rates were not measured, although a qualitative flow description was recorded (e.g., weak or strong flow) and rainfall events were noted. Nitrate N, NH_4-N, particulate organic N (PON), and PO_4-P were measured. Unfortunately, dissolved organic nitrogen (DON) and TP were not measured, so total concentrations of N and P were not available from the study.

Weyerhaeuser Multi-Tract Study

Weyerhaeuser Company measured the nutrient concentrations in outflow coming from a broad cross-section of forested subwatersheds between 1997 and 2000. The goal was to determine whether the high NO_3-N concentrations observed in the Parker Tract study site could be found in similar locations near the Suffolk Scarp. Weyerhaeuser sampled the outlets of 11 forest subwatersheds ranging in size from 371 to 2,272 ha (Fig. 2.11). The forest canopy in these subwatersheds was predominantly loblolly pine, with some natural stands of pine and/or hardwoods at some of the sites. All sites had drainage systems consisting of interior field ditches connected to roadside collector ditches. The predominant soil types in each subwatershed were generally either mineral or organic as noted:

- **Morrison Tract**–This 2,272 ha subwatershed is located in Gates County 21 km north of Hertford, N.C., and is part of the Great Dismal Swamp. It is east of the Suffolk Scarp at an elevation of about 6 m and has interior ditch spacing of about 100 m. Outflow from the site drains south to an unnamed tributary of the Perquimans River. The forest consists of early- to mid-rotation loblolly pine stands in the south and an area of natural pine in the north. Soils are organic mucks in the Belhaven and Pungo series and are highly acidic. Along the southern boundary of the subwatershed and at the watershed outlet, there is a narrow band of sandy loam soil in the Icaria series (fine-loamy over sandy or sandy-skeletal, siliceous, semiactive, thermic Typic Umbraquults).
- **Kramer Tract**–This 807 ha subwatershed is located in Perquimans County east of Suffolk Scarp at the south end of Bear Swamp. Elevation is approximately 6 m. Interior ditch spacing is 200 m. The outlet drains into Bethel Creek, which is a tributary of the Yeopim River. The forest at the site is predominantly late-rotation loblolly pine. Soils are mineral, mainly Cape Fear and Portsmouth series loams, and Roanoke and Tomotley series loams.
- **Hyde 15**–This 496 ha subwatershed is located in Hyde County east of the Pungo River section of the Intracoastal Waterway (ICW) and 18 km east of Belhaven, N.C. This low-elevation site (less than 3 m) is drained by interior ditches that are mostly 100 m apart; a few areas have closer spacing at 60 m. Outflow from the subwatershed goes to the ICW. The forest at the site is mainly mid- to late-rotation loblolly pine. Near the drainage system outlet there are mineral soils: Portsmouth loam and Brookman clay loam (fine, mixed, superactive, thermic Umbric Endoaqualfs). The southern portion of the drainage area has Pettigrew series muck soils (fine, mixed, semiactive, nonacid, thermic Histic Humaquepts).

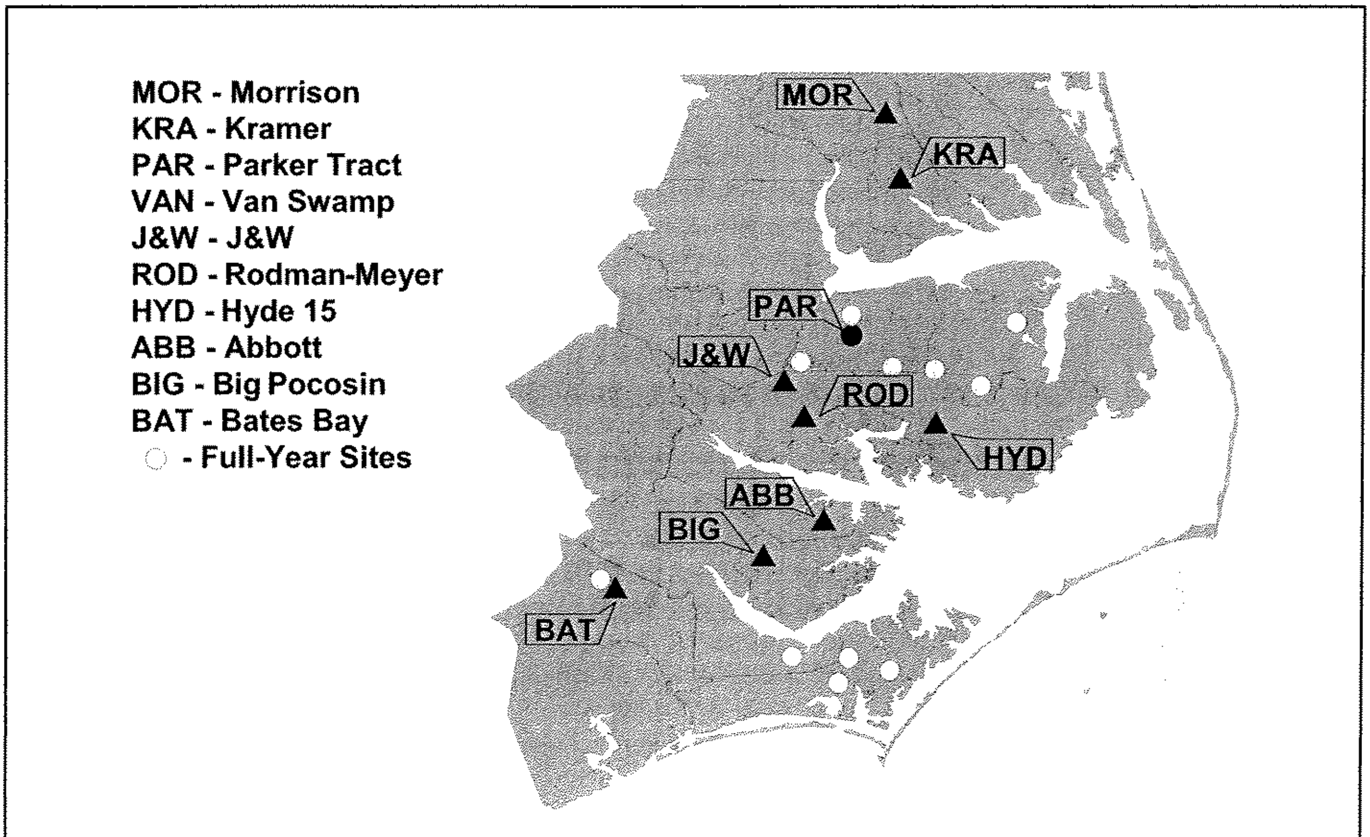


Figure 2.11. Map of eastern North Carolina showing the multi-tract study sites. The full-year study sites are identified in Figure 2.1.

- **Rodman-Meyer**–This 1,854 ha subwatershed is located in Beaufort County and occupies the southern half of Van Swamp. It is on the east margin of the Suffolk Scarp at an elevation of 6 to 12 m. N.C. 32 forms the eastern boundary of the site, which is 5 km north of Pinetown, N.C. Ditches on this tract are 100 m apart, and outflow drains to the Acre Swamp branch of Pungo Creek and eventually to the Pungo River. The forest at the site includes early- to mid-rotation loblolly pine and natural pine stands. Soils are mainly organic mucks in the Croatan and Dare series. Along N.C. 32, the soils are sandy loams in the Torhunta Series. Near the subwatershed outlet, there are acidic mineral soils in the Bayboro series (fine, mixed, semiactive, thermic Umbric Paleaquults).
- **J & W Tract**–This large, continuous forest tract is located in Beaufort County west of Suffolk Scarp and was formerly known as Hall Swamp. The swamp forms the headwaters of several streams that drain either north to the Roanoke River or south or east to the Pamlico and Pungo rivers. Elevations of this interbasin swamp range from about 12 to 15 m. Four subwatersheds in this tract were included in the study; three are on the west side, and one is on the east.
- **J&W 1**–This 1,300 ha subwatershed is on the west side of the tract and drains to the Hardison Mill branch of Sweetwater Creek, a tributary of the Roanoke River. Ditch spacing is 100 and 200 m, and the forest is mainly loblolly pine. The soils in the subwatershed are Bethera loam (fine, mixed, semiactive, thermic Typic Paleaquults) and Pantego loam; Lynchburg sandy loam (fine-loamy, siliceous, semiactive, thermic Aeric Paleaquults); and Rains sandy loam. The 100 m ditch spacing is mainly in the northeast part of the watershed where there are Bethera soils.
- **J&W 2**–This 750 ha subwatershed is located in the northwest corner of the tract. Its outflow enters the Deep Run Swamp branch of Gardners Creek (Roanoke River system). Ditch spacing is 100 and 200 m, and the forest is mainly loblolly pine. Soils are loams and sandy loams in four series: Bethera loam, Rains sandy loam, Lynchburg sandy loam, and Pantego loam.
- **J&W 3**–This 1,552 ha subwatershed is located in the southwest portion of the tract, and the forest is mainly mid-rotation loblolly pine. Ditch spacing is 100 and 200 m. The drainage system outlet, on the south side of the subwatershed, flows into a branch of Hardison Mill Creek, which enters Sweetwater Creek. Soils are mainly mineral in four series: Bayboro loam, Pantego loam, Leaf silt loam (fine, mixed, active, thermic Typic Albaquults), and Rains loam. Croatan muck occurs near the outlet and in the southern portion of the subwatershed.
- **J&W 4**–This 371 ha subwatershed is near the southeast side of the tract and shares some of the same soil character. Ditch spacing is 200 m, and the forest is mainly loblolly pine. The outflow enters the Swamp Fork of Pungo Swamp Creek, a tributary of Pungo Creek. Bayboro loam and Leaf silt loam are major soils in this area. Lynchburg series sandy loam also occurs as a minor component.
- **Abbott Tract**–This low-elevation subwatershed (less than 5 m) is located in Beaufort County as a 580 ha portion of Gum Swamp 11.3 km east of Aurora, N.C., between the Bay and Pamlico rivers. Forest stands are mainly early- and late-rotation loblolly pine and have an interior ditch spacing of 200 m, except for a few areas with 70 m spacing. Drainage from the subwatershed enters Campbell Creek, a tributary of Goose Creek (Pamlico River system). Soils are mainly organic muck of the Dare and Ponzer series. A portion of the drainage area near the subwatershed outlet has mineral soils in the Wasda series.
- **Big Pocosin**–This 819 ha subwatershed is located in Craven County and drains to Little Swift Creek and eventually the Neuse River via Swift Creek. Outflows to the north enter several branches of Blounts Creek, which flow into the Pamlico. The site is 22.5 km north of New Bern and has an average elevation of 6 m. The ditch spacing is mainly 200 m, although ditches are 100 m apart in the north part of the subwatershed. The forest consists of mid- to late-rotation loblolly pine. Soils are in the Bayboro and Leaf series.
- **Bates Bay**–This 1,050 ha subwatershed is a portion of the Jones 5 Tract and is part of an interbasin flat (el. 15 to 18 m) formerly known as the Great Dover Swamp. Outflow from the subwatershed sampled drains to the Neuse River via Core Creek. Ditch spacing is 100 m in the upper portion of the drainage area with organic muck soils and 200 m toward the outlet. The forest is mostly loblolly pine with early-rotation stands in the upper subwatershed and mainly mid- to late-rotation pine stands and a hardwood area on the mineral soils. Approximately one-third of the drainage area originates from Bates Bay, a deep peat deposit near Dover, with an organic muck soil in the Croatan series. Soils in the downslope area of the subwatershed are mainly sandy loams: Torhunta and Stockade (fine-loamy, mixed, superactive, thermic Umbric Endoaqualfs). Minor soils in this area include Murville sand (sandy, siliceous, thermic Umbric Endoaquods) and Woodington sandy loam.

The sampling program focused on winter and spring, the times when maximum NO_3-N concentrations were observed in the Parker Tract/Kendricks Creek drainage area. Outflow from each subwatershed was collected as a grab sample at its outlet typically three to four times per quarter. For surveys conducted in 1998, 1999, and 2000, sampling was conducted over one to two days to minimize hydrological differences among the sites for a given set of samples. The water samples were preserved with sulfuric acid in the field and stored on ice during transport to the Weyerhaeuser New Bern Analytical Laboratory. When there was no outflow from a subwatershed, field measurements were not taken and water samples were not collected. Samples that were collected were analyzed for TKN, NO_3-N, NH_4-N, and TP.

SECTION 3 - BASELINE HYDROLOGY

Rainfall in eastern North Carolina is highly variable on an annual and seasonal basis (Table 3.1). Summer has the highest average rainfall. The greatest year-to-year variation in seasonal rainfall also occurs in the summer months since much of the rainfall during these times occurs in highly variable convective and tropical storms. The rest of the rainfall for the year is fairly evenly distributed among the fall, winter, and spring seasons, with the least rainfall occurring in the fall. While the highest rainfall occurs in the summer, most of the excess water (rainfall - potential evapotranspiration [PET]) occurs during the winter. On average, rainfall exceeds potential evapotranspiration every quarter with the exception of spring, when a small deficit (24 to 42 mm) occurs. Average annual excess water for eastern North Carolina ranges from 390 to 415 mm, which is about 30% of average annual rainfall.

Carteret County - Carteret 7

The D1 watershed represented a managed forest east of the Suffolk Scarp with internal field ditches and mineral soil. Annual rainfall at D1 during 1988 to 1995 averaged 1,497 mm/yr (Table 3.2), which was somewhat higher than the 40-year average (1951 to 1990) of 1,379 mm/yr for nearby Morehead City, N.C. (Table 3.1). The dry years during the study period were 1990 and 1995, when 1,236 mm and 1,252 mm of precipitation fell, respectively, while 1989 and 1992 were the wettest years with 1,875 mm and 1,619 mm, respectively (Table 3.2). Annual outflow for 1988 to 1995 averaged 462 mm and was significantly correlated with precipitation ($p=0.02$). Variation in annual outflow ($CV=0.33$) was greater than for precipitation ($CV=0.14$), with minimum and maximum outflow values of 240 mm (1990) and 658 mm (1989), respectively. Average hydrologic response (outflow/precipitation) for the D1 watershed during 1988 to 1995 was 30%, with an overall range of 19 to 38%. Loss of the remaining water at the site occurred through evapotranspiration (52%), interception (15%), and lateral seepage (3%); deep seepage at the site was minimal due to an impermeable layer at 3.0 m (Amatya et al., 1996; McCarthy et al., 1991).

On a seasonal basis, outflow from the D1 watershed was highest during the winter quarter (249 mm) at 63% of total rainfall (Table 3.2). The overall range in hydrologic response during the winter period was 26 to 90% for the eight-year study period, with outflow

Table 3.1. Quarterly and annual precipitation (P), estimated potential evapotranspiration (PET), and excess water (P-PET) for selected eastern North Carolina weather stations. Values (mm) shown are the average, standard deviations, and coefficients of variation for data from 1951 to 1990. PET was calculated using the Thornthwaite method with correction coefficients presented by Amatya et al. (1995).

	Winter Quarter			*Spring Quarter*			*Summer Quarter*			*Fall Quarter*			*Annual Totals*		
Site/Statistic	***P***	***PET***	***P-PET***	***P***	***PET***	***P-PET***	***P***	***PET***	***P-PET***	***P***	***PET***	***P-PET***	***P***	***PET***	***P-PET***
Plymouth															
Average	310	117	193	313	337	-24	429	333	96	244	118	126	1,295	905	390
Std Dev	80	33	95	101	32	98	121	33	116	93	19	95	191	72	187
CV	0.26	0.29	0.49	0.32	0.10	-4.0	0.28	0.10	1.2	0.38	0.16	0.75	0.13	0.08	0.48
New Bern															
Average	306	138	168	317	353	-35	480	354	135	257	130	127	1,360	966	394
Std Dev	86	34	97	91	23	81	177	30	178	89	22	89	206	62	191
CV	0.28	0.24	0.58	0.29	0.09	-2.3	0.37	0.09	1.3	0.37	0.17	0.70	0.15	0.06	0.48
Morehead City															
Average	314	133	180	300	342	-42	471	344	127	294	145	149	1,379	964	415
Std Dev	96	35	109	107	32	99	177	40	170	110	20	111	245	59	234
CV	0.31	0.27	0.61	0.35	0.09	-2.4	0.37	0.12	1.3	0.37	0.14	0.74	0.17	0.06	0.57

Table 3.2. Carteret 7 hydrology - D1. Quarterly and annual outflow (Q) and precipitation (P) values are shown for 1988 to 1995.

	Winter Quarter			Spring Quarter			Summer Quarter			Fall Quarter			Annual Totals		
Year	Q mm	P mm	Q/P %	Q mm	P mm	Q/P %	Q mm	P mm	Q/P %	Q mm	P mm	Q/P %	Q mm	P mm	Q/P %
1988*	178	336	53%	25	346	7%	59	545	11%	0	179	0%	262	1,406	19%
1989	100	385	26%	113	378	30%	137	683	20%	308	429	72%	658	1,875	35%
1990	140	291	48%	94	250	38%	0	433	0%	6	262	2%	240	1,236	19%
1991	286	420	68%	15	243	6%	84	594	14%	107	319	34%	492	1,576	31%
1992	307	430	71%	39	276	14%	115	597	19%	139	316	44%	600	1,619	37%
1993	341	439	78%	119	283	42%	0	291	0%	124	516	24%	584	1,529	38%
1994	292	420	70%	25	220	11%	0	413	0%	96	427	22%	413	1,480	28%
1995	351	390	90%	0	286	0%	6	292	2%	88	284	31%	445	1,252	36%
Average	249	389	63%	54	285	19%	50	481	8%	109	342	29%	462	1,497	30%
Std Dev	96	51	20%	47	53	16%	57	146	9%	95	109	23%	154	208	8%
CV	0.39	0.13	0.32	0.88	0.19	0.85	1.13	0.30	1.06	0.88	0.32	0.80	0.33	0.14	0.25

Note: (*) tract D2 outflow used for 1988 winter quarter due to 0.7 m weir setting for D1.

significantly ($p<0.05$) correlated with winter precipitation ($r=0.71$). In contrast, spring and summer outflow was low, averaging 54 mm and 50 mm, respectively, despite a combined total of 766 mm of rainfall. The hydrologic response during spring and summer was correspondingly low at 19 and 8%, respectively. Summer outflow was strongly correlated with rainfall ($r=0.92$, $p=0.001$), despite low average outflow for the study period. Outflow increased again during the fall quarter (avg. 109 mm), accounting for 29% of the rainfall. Outflow was more variable than rainfall for all quarters. Variability of outflow was least during the winter quarter (CV=0.39) compared to the spring (CV=0.88), summer (CV=1.13), and fall (CV=0.88). Rainfall was also least variable for the winter quarter.

Carteret County - Isaac Creek

Rainfall at Isaac Creek, located east of the Suffolk Scarp, was highest during the summer in most years. Overall, annual rainfall for this 10-year study (1986 to 1995) varied from 1,038 mm/yr in 1990 to 1,546 mm/yr in 1989 (Table 3.3). The mean annual rainfall value for the 10-year period, when all years are included, was 1,265 mm, which was less than the long-term mean at Morehead City, N.C. (Table 3.1). Rainfall during the summer was significantly higher ($p<0.007$) than in all other seasons; at 457 mm, on average, it accounted for 36% of the annual total (Table 3.3). For other seasons, mean values for the period were from 240 to 296 mm, with the lowest value for the spring. Years with above or below average rainfall generally reflected an abnormally high or low value (100 mm) for only one quarter rather than throughout the year. The exceptions to this simple pattern were 1989 and 1993, when rainfall substantially deviated from seasonal means for two seasons.

The monitoring sites in the Isaac Creek study represented a ditched managed forest on organic soil (B); an unditched natural forest on organic soil (UD); a ditched, mixed managed and natural forest on mostly mineral soil (D); and a ditched, mixed managed and natural forest on mineral soil (ABC). Outflow measured at these sites varied considerably among different years of the study (Tables 3.3 and 3.4). For each location, annual outflow volumes during the high precipitation years (1989, 1991, and 1992) were nearly twice as high as flow volumes during the low precipitation year, 1990. Despite this general correspondence between annual rainfall and outflow volumes, regression analysis revealed that rainfall explained only 45, 56, and 79% of interannual variations in outflow at the ABC, D, and B outlets, respectively. Outflow from the UD block was not significantly related to annual rainfall. Notably, the fraction of annual rainfall leaving the UD block as outflow was significantly related to rainfall, indicating the outflow-rainfall relationship is nonlinear. As observed at Carteret 7, variations in annual outflows for all sites (CV=0.22 for ABC, CV=0.22 for D, CV=0.27 for B, and CV=0.43 for UD) were greater than variations in annual precipitation (CV=0.12 for ABC and B, CV=0.8 for D, and CV=0.13 for UD).

A comparison of outflow volumes from the four monitored outlets indicates significantly lower values ($p<0.02$) for blocks B and UD than at the watershed outlets (Tables 3.3 and 3.4). Mean outflow rates for the study period were 424 and 384 mm/yr for the ABC and D outlets, respectively, compared with values of 327 and 194 mm/yr, respectively, for blocks B and

Table 3.3. Isaac Creek watershed hydrology - managed blocks. Quarterly and annual outflow (Q) and precipitation (P) are shown for 1986 to 1995. For years in which outflow was affected by timber harvests, values are underlined and not used in calculations.

	Winter Quarter			*Spring Quarter*			*Summer Quarter*			*Fall Quarter*			*Annual Totals*		
Block/Year	**Q** *mm*	**P** *mm*	**Q/P** %	**Q** *mm*	**P** *mm*	**Q/P** %	**Q** *mm*	**P** *mm*	**Q/P** %	**Q** *mm*	**P** *mm*	**Q/P** %	**Q** *mm*	**P** *mm*	**Q/P** %
Block B															
1986	39	166	23%	21	167	12%	96	508	19%	26	224	11%	182	1,065	17%
1987	182	308	59%	44	207	21%	144	482	30%	17	177	10%	389	1,175	33%
1988	129	314	41%	74	287	26%	149	498	30%	10	155	6%	362	1,255	29%
1989	98	325	30%	108	323	33%	38	569	7%	217	329	66%	461	1,546	30%
1990	92	236	39%	58	227	25%	72	339	21%	13	236	5%	235	1,038	23%
1991	157	292	54%	43	232	18%	251	611	41%	89	299	30%	539	1,434	38%
1992	144	286	50%	105	255	41%	131	404	32%	84	286	29%	464	1,231	38%
1993	138	349	39%	57	257	22%	8	249	3%	72	396	18%	276	1,251	22%
1994	145	380	38%	20	167	12%	35	496	7%	135	326	41%	335	1,369	24%
1995	60	299	20%	4	280	2%	86	411	21%	137	292	47%	287	1,282	22%
Average	113	306	36%	47	241	18%	79	459	17%	88	271	29%	327	1,278	25%
Std Dev	50	68	13%	36	62	11%	55	104	11%	78	88	23%	90	151	5%
CV	0.45	0.22	0.36	0.77	0.26	0.57	0.69	0.23	0.67	0.89	0.33	0.80	0.27	0.12	0.22
ABC Outlet															
1986	127	166	76%	33	167	20%	168	508	33%	34	224	15%	361	1,065	34%
1987	236	308	77%	47	207	23%	106	482	22%	30	177	17%	420	1,175	36%
1988	153	314	49%	75	287	26%	151	498	30%	19	155	12%	398	1,255	32%
1989	106	325	33%	125	323	39%	128	569	23%	244	329	74%	604	1,546	39%
1990	107	236	45%	75	227	33%	54	339	16%	56	236	24%	292	1,038	28%
1991	176	292	60%	42	232	18%	264	611	43%	109	299	37%	591	1,434	41%
1992	213	286	75%	104	255	41%	161	404	40%	116	286	41%	594	1,231	48%
1993	219	349	63%	93	257	36%	0	249	0%	148	396	37%	461	1,251	37%
1994	213	380	56%	26	167	15%	29	496	6%	174	326	53%	442	1,369	32%
1995	190	299	63%	12	280	4%	54	411	13%	95	292	33%	351	1,282	27%
Average	175	316	55%	65	250	25%	75	435	16%	110	273	36%	424	1,274	33%
Std Dev	53	45	14%	39	53	12%	55	110	10%	83	87	22%	98	158	4%
CV	0.31	0.14	0.26	0.43	0.21	0.49	0.75	0.25	0.66	0.60	0.32	0.61	0.22	0.12	0.13
D Outlet															
1986	91	166	55%	7	167	4%	127	508	25%	15	224	7%	241	1,065	23%
1987	255	308	83%	37	207	18%	69	482	14%	7	177	4%	368	1,175	31%
1988	168	314	53%	59	287	21%	127	498	25%	3	155	2%	357	1,255	28%
1989	114	325	35%	175	323	54%	129	569	23%	293	329	89%	711	1,546	46%
1990	137	236	58%	146	227	64%	0	339	0%	28	236	12%	311	1,038	30%
1991	171	292	58%	56	232	24%	296	611	48%	84	299	28%	607	1,434	42%
1992	194	286	68%	70	255	28%	105	404	26%	119	286	41%	488	1,231	40%
1993	260	349	74%	97	257	38%	0	249	0%	83	396	21%	440	1,251	35%
1994	188	380	49%	37	167	22%	31	496	6%	170	326	52%	425	1,369	31%
1995	224	299	75%	36	280	13%	105	411	26%	141	292	48%	506	1,282	39%
Average	170	303	54%	52	228	22%	88	441	18%	74	262	25%	384	1,233	31%
Std Dev	78	74	20%	29	55	9%	60	100	13%	68	93	20%	111	103	8%
CV	0.46	0.24	0.37	0.43	0.24	0.43	0.75	0.23	0.69	0.60	0.35	0.82	0.22	0.08	0.25

UD. Examining the seasonal distributions of outflow reveals that during the winter period a larger fraction of rainfall flows from the ABC and D watershed outlets than from blocks B and UD. Data in the comparison were normalized to annual rainfall (outflow/rainfall) before seasonal values were calculated to remove variations in outflow data due to differences in rainfall among years. All locations showed a consistent seasonal pattern, with relative outflow being significantly higher during winter months ($p<0.05$) than in other seasons and lowest during the summer. Outflow for the ABC and D watershed outlets during winter was 54 to 55% of rainfall compared with only 28 to 36% for blocks B and UD. As observed at Carteret 7, variations in winter outflows for all sites were less than variations in spring, summer, and fall outflows.

A factor contributing to the difference between the two watersheds (ABC and D) and the two blocks (B and UD) is the lower hydraulic conductivity of the soil in blocks B and UD. The heterogeneous mineral and organic soils of blocks C and D had higher conductivities than organic mucks for blocks B and UD along the plateau of the interstream divide (Amatya et al., 1997). This difference in soil conductivity between the organic flat and the downslope blocks implies that more water would be retained on the organic flat blocks due to slower drainage in the winter dormancy period. The absence of drainage ditches in the UD block would also contribute to the fact that the lowest outflow occurs from this block.

Jones County

Annual rainfall for the Jones County study, located west of the Suffolk Scarp, varied from 1,227 mm/yr in 1982 to 1,407 mm/yr in 1983 (Table 3.5). The mean annual rainfall for the three-year period (1,289 mm) was less than the long-term average at New Bern, N.C. (1,360 mm) (Table 3.1). Rainfall during summer months (401 mm) was only slightly higher than in the winter months (378 mm). The mean value for the spring was 312 mm, and the mean value for the fall was 195 mm. Rainfall was above normal for the winter and below normal for the summer and fall compared with long-term records from New Bern (Table 3.1).

Outflows from the J2 and J3 blocks of managed young loblolly pine stands on ditched mineral soils in the Weyerhaeuser Jones 5 Tract were very similar in amount and seasonal distribution (Table 3.5). Outflow from J1 was only monitored for a portion of the study period, so it is not included in this summary. Outflow from the J2 and J3 blocks averaged 475 mm/yr for the three years with complete data (1982 to 1984), which accounted for approximately 37% of total rainfall. Annual hydrologic response varied from 31% in 1984 (outflow = 381 mm) to 41% in 1983 (average outflow = 572 mm). Variations in annual outflows for both sites (CV=0.20) were greater than variations in annual precipitation (CV=0.08).

Outflow was highest during the winter, when trees are dormant and

Table 3.4. Isaac Creek hydrology - block UD. Quarterly and annual outflow (Q) and precipitation (P) are shown for 1986 to 1995. Values between 1991 summer quarter and 1992 winter quarter were affected by a lower weir setting. They are underlined and not used in calculations.

	Winter Quarter			Spring Quarter			Summer Quarter			Fall Quarter			Annual Totals		
Year	Q mm	P mm	Q/P %	Q mm	P mm	Q/P %	Q mm	P mm	Q/P %	Q mm	P mm	Q/P %	Q mm	P mm	Q/P %
1986	19	166	11%	0	167	0%	136	508	27%	4	224	2%	160	1,065	15%
1987	109	308	35%	19	207	9%	22	482	5%	0	177	0%	150	1,175	13%
1988	141	314	45%	24	287	9%	83	498	17%	0	155	0%	249	1,255	20%
1989	48	325	15%	63	323	19%	71	569	12%	141	329	43%	323	1,546	21%
1990	46	236	20%	38	227	17%	22	339	6%	10	236	4%	116	1,038	11%
1991	111	292	38%	4	232	2%	232	611	38%	82	299	27%	428	1,434	30%
1992	0	286	0%	34	255	13%	0	404	0%	0	286	0%	34	1,231	3%
1993	132	349	38%	42	257	16%	0	249	0%	72	396	18%	246	1,251	20%
1994	118	380	31%	4	167	3%	0	496	0%	32	326	10%	155	1,369	11%
1995	57	299	19%	0	280	0%	27	411	7%	68	292	23%	152	1,282	12%
Average	87	297	28%	23	240	9%	40	440	8%	36	269	11%	194	1,248	15%
Std Dev	44	63	12%	23	57	8%	47	99	9%	49	78	15%	71	164	4%
CV	0.51	0.21	0.43	0.99	0.24	0.88	1.17	0.23	1.11	1.34	0.29	1.31	0.43	0.13	0.27

Table 3.5. Jones County hydrology - J2 and J3 blocks. Quarterly and annual outflow (Q) and precipitation (P) are shown for 1981 to 1984.

	Winter Quarter			Spring Quarter			Summer Quarter			Fall Quarter			Annual Totals		
Block/Year	Q mm	P mm	Q/P %	Q mm	P mm	Q/P %	Q mm	P mm	Q/P %	Q mm	P mm	Q/P %	Q mm	P mm	Q/P %
J2 Block															
1981				160	396	40%	150	472	32%	0	36	0%			
1982	236	328	72%	30	246	12%	20	414	5%	191	239	80%	478	1,227	39%
1983	376	467	80%	142	287	50%	0	300	0%	23	353	6%	541	1,407	38%
1984	295	340	87%	56	320	17%	36	419	8%	5	152	3%	391	1,232	32%
Average	302	378	80%	97	312	30%	51	401	11%	55	195	22%	470	1,289	36%
Std Dev	70	77	7%	64	63	18%	67	73	14%	91	134	38%	75	103	4%
CV	0.23	0.20	0.09	0.65	0.20	0.60	1.31	0.18	1.25	1.67	0.69	1.71	0.16	0.08	0.11
J3 Block															
1981				173	396	44%	150	472	32%	0	36	0%			
1982	206	328	63%	30	246	12%	23	414	6%	208	239	87%	467	1,227	38%
1983	384	467	82%	165	287	58%	3	300	1%	51	353	14%	602	1,407	43%
1984	282	340	83%	61	320	19%	23	419	5%	5	152	3%	371	1,232	30%
Average	290	378	76%	107	312	33%	50	401	11%	66	195	26%	480	1,289	37%
Std Dev	89	77	11%	72	63	21%	68	73	14%	98	134	41%	116	103	6%
CV	0.31	0.20	0.15	0.67	0.20	0.64	1.36	0.18	1.29	1.48	0.69	1.57	0.24	0.08	0.17

evapotranspiration is reduced (Table 3.1). Outflow for the winter quarters in the study averaged 296 mm, which accounted for 78% of winter rainfall (378 mm) (Table 3.5). Mean outflows for other quarters were markedly less at: 102 mm (spring); 50 mm (summer); and 61 mm (fall). The minimum quarterly outflow that occurred during the summer contrasts with the maximum seasonal rainfall (401 mm), which also occurred in the summer. These contrasting patterns illustrate the relatively high evapotranspiration losses from managed forests even during the early rotational period for loblolly pine. Variability of outflow from both J2 and J3 was least during the winter quarter (CV=0.27) compared to the spring (CV=0.66), summer (CV=1.33), and fall (CV=1.57).

Tyrrell County

Annual rainfall for three undeveloped sites in Tyrrell County, N.C., located east of the Suffolk Scarp, averaged 1,222, 1,216, and 1,182 mm, respectively, for T102, T104, and T107 (Table 3.6). These rainfall averages, over a three-year period from 1976 to 1979, were somewhat less than the long-term average for Plymouth, N.C. (1,295 mm) (Table 3.1). Annual rainfall ranged from 975 mm/yr at one site in 1976 to 1977 to a high of 1,580 mm/yr at another site in 1977 to 1978. For this study, a year went from summer through the following spring (Table 3.6). The T102 site (natural forest on ditched mineral soil) had the lowest average annual outflow (408 mm), while average annual outflow for T107 (natural forest on ditched shallow organic soil) and T104 (natural forest on unditched deep organic soil) was 553 and 538 mm, respectively. Annual outflow ranged from 257 mm to 904 mm. When annual outflow for each site is compared with rainfall for the three complete years of the study, outflows accounted for 26 to 58% of annual rainfall, with higher hydrological response values observed in 1977 to 1978 at all three sites. Variations in annual outflows for all sites (CV=0.40 for T102, CV=0.47 for T104, and CV=0.55 for T107) were greater than variations in annual precipitation (CV=0.19 for T102, CV=0.26 for T104, and CV=0.28 for T107).

Seasonal outflow was highest during the winter and lowest during the summer (Table 3.6). For the three sites, average quarterly outflow ranged from 221 to 274 mm during winter months, accounting for 78 to 95% of the winter rainfall and almost half of the annual outflow. In contrast, summer outflow ranged from 29 to 68 mm at the sites, accounting for only 8 to 19% of rainfall. As observed in the other studies, the variability of outflow from all three sites was less in the winter than in the spring, summer, and fall.

Comparing outflow data for the three sites, the mean annual hydrologic response from the two organic soils (T104 and T107) was higher at 43 to 45% than the mean annual hydrologic response of 33% for the mineral soil (T102) (Table 3.6). Skaggs et al. (1980) attributed the seasonal lowering of the water table at each site mainly to evapotranspiration rather than subsurface drainage. Greater transpiration by the pine overstory at the mineral site than by the low shrubs at the organic sites may account for the lower average outflow from the mineral soil site as compared with the organic sites. The hydrologic responses for the organic soil sites were much higher than those reported for other sites. Since the weirs were submerged at the sites during some periods of high rainfall, some of the estimated flow may have been too high.

Washington County

Annual rainfall for the Washington County study, located east of the Suffolk Scarp, varied from 1,118 mm/yr in 1993 to 1994 to a high of 1,320 mm/yr in 1994 to 1995 (Table 3.7). For this study, a year went from summer through the following spring. The mean annual rainfall for the three-year period (1,218 mm) was somewhat less than the long-term average at Plymouth, N.C. (1,295 mm) (Table 3.1). Rainfall during summer months (370 mm) was only slightly higher than for the winter months (349 mm) (Table 3.7). Mean rainfall was 344 mm for the spring months and 244 mm for the fall. Average rainfall amounts were above normal for the winter and below normal for the summer.

Average annual outflow was very low for the Washington County site (a natural hardwood forest on unditched mineral soil), with annual values ranging from 94 mm to 269 mm (Table 3.7). Outflow was highest during winter months and extremely low during the fall. During the winter quarter, average outflow was 153 mm for 1994 to 1996, accounting for 46% of the average winter precipitation, and hydrologic

Table 3.6. Tyrrell County hydrology - natural blocks. Quarterly and annual outflow (Q) and precipitation (P) are shown for 1976 to 1979. Soils types are: (T102) mineral; (T104) deep organic; and (T107) shallow organic.

	Winter Quarter			*Spring Quarter*			*Summer Quarter*			*Fall Quarter*			*Annual Totals**		
Site and Year	**Q mm**	**P mm**	**Q/P %**	**Q mm**	**P mm**	**Q/P %**	**Q mm**	**P mm**	**Q/P %**	**Q mm**	**P mm**	**Q/P %**	**Q mm**	**P mm**	**Q/P %**
T102 Block															
1976							36	391	9%	69	231	30%	257	975	26%
1977	140	155	90%	13	198	6%	5	333	2%	76	345	22%	579	1,440	40%
1978	307	396	78%	191	366	52%	46	353	13%	8	191	4%	389	1,250	31%
1979	216	330	65%	119	376	32%									
Average	221	294	78%	108	313	30%	29	359	8%	51	256	19%	408	1,222	33%
Std Dev	84	125	12%	89	100	23%	21	30	6%	38	80	13%	162	234	7%
CV	0.38	0.42	0.16	0.83	0.32	0.76	0.73	0.08	0.74	0.74	0.31	0.71	0.40	0.19	0.22
T104 Block															
1976							43	353	12%	43	234	18%	300	986	30%
1977	127	178	71%	86	221	39%	36	381	9%	251	437	58%	803	1,580	51%
1978	277	338	82%	239	424	56%	124	343	36%	10	109	9%	513	1,082	47%
1979	267	323	83%	112	307	36%									
Average	224	279	79%	146	318	44%	68	359	19%	102	260	28%	538	1,216	43%
Std Dev	84	88	6%	82	102	11%	49	20	15%	131	165	26%	252	319	11%
CV	0.37	0.32	0.08	0.56	0.32	0.25	0.73	0.05	0.77	1.29	0.64	0.90	0.47	0.26	0.25
T107 Block															
1976							107	399	27%	104	234	45%	406	1,059	38%
1977	173	196	88%	23	231	10%	58	386	15%	269	450	60%	904	1,552	58%
1978	396	338	117%	180	378	48%	0	157	0%	0	168	0%	348	935	37%
1979	254	315	81%	94	295	32%									
Average	274	283	95%	99	301	30%	55	314	14%	124	284	35%	553	1,182	45%
Std Dev	113	76	19%	79	74	19%	53	136	13%	136	147	31%	306	326	12%
CV	0.41	0.27	0.20	0.80	0.25	0.64	0.97	0.43	0.96	1.09	0.52	0.89	0.55	0.28	0.27

* Annual totals are for the summer quarter through the following spring.

Table 3.7. Washington County wetland site hydrology. Quarterly and annual outflow (Q) and precipitation (P) are shown for 1993 to 1996.

	Winter Quarter			*Spring Quarter*			*Summer Quarter*			*Fall Quarter*			*Annual Totals**		
Year	**Q mm**	**P mm**	**Q/P %**	**Q mm**	**P mm**	**Q/P %**	**Q mm**	**P mm**	**Q/P %**	**Q mm**	**P mm**	**Q/P %**	**Q mm**	**P mm**	**Q/P %**
1993							0	151	0%	0	248	0%	94	1,118	8%
1994	77	396	20%	17	324	5%	0	368	0%	1	197	1%	252	1,320	19%
1995	212	334	64%	39	423	9%	40	323	13%	3	289	1%	269	1,214	22%
1996	170	318	54%	55	284	19%	142	640	22%						
Average	153	349	46%	37	344	11%	46	370	9%	1	244	1%	205	1,218	17%
Std Dev	69	41	23%	19	71	7%	67	203	11%	2	46	1%	97	101	7%
CV	0.45	0.12	0.51	0.52	0.21	0.65	1.47	0.55	1.24	1.15	0.19	1.01	0.47	0.08	0.44

* Annual totals are for the summer quarter through the following spring.

response values for individual years ranged from 20 to 64%. Outflow during the fall quarter was extremely low in all years (1 to 3 mm), despite 197 to 289 mm of rain. Outflow in spring and summer quarters varied considerably among years and averaged 11% and 9%, respectively, of rainfall. Outflow in spring and summer during individual years ranged from 17 to 55 mm and from 0 to 142 mm, respectively, with the highest outflow in 1996 for both seasons. Maximum summer outflow during 1996 was associated with very high summer rains associated with tropical storms (640 mm). Variability of outflow from the site was least during the winter quarter (CV=0.45) compared to the spring (CV=0.52), summer (CV=1.47), and fall (CV=1.15).

Parker Tract

Annual rainfall measured at the primary rain gauge (R6) on the Parker Tract study site (located east of the Suffolk Scarp) varied from 955 mm/yr in 1997 to 1,410 mm/yr in 1996 (Table 3.8). The mean annual rainfall value for the three-year period (1,214 mm) was somewhat less than the long-term average at Plymouth, N.C. (1,295 mm) (Table 3.1). Rainfall during summer months ranged from 218 mm in 1998 to 561 mm in 1996 and was, on average, higher (346 mm) than for the winter months (322 mm) (Table 3.8). Mean rainfall was 257 mm for the spring months and 290 mm for the fall months. Average quarterly rainfall amounts were above normal for the fall, below normal for the summer and spring, and near normal for the winter.

Outflow rates measured at blocks F4, F5, and F7 were much lower than expected, leading to the discovery of a significant seepage loss across the southern boundary of the Parker Tract. A road along this boundary separates the Parker Tract from a large canal that drains the adjacent agricultural area. This road was constructed by piling the spoil from the ditches and canals onto the highly organic soil and the remains of trees on or in the soil. The logs and branches of these trees provided conduits under the road, resulting in large seepage losses from the forested blocks to the adjacent drainage canal; consequently, outflow from blocks F4, F5, and F7 is not considered in this report. To remedy this situation, a deep trench was dug along the road in 1999 and backfilled with mineral soil.

The S4 watershed included a mixture of forested blocks, some with mostly managed stands and about one third of the area with natural stands. These blocks were mostly on ditched organic soils with about one third of the area on ditched mineral soils. Annual outflow for this watershed averaged 302 mm and ranged from 145 to 478 mm (Table 3.8). Outflow from the site was highest during winter months and lowest during the spring and summer. During the winter quarter, average outflow was 161 mm, accounting for 50% of the average winter precipitation, and hydrologic response values for individual years ranged from 40 to 57%. Average hydrologic response was 15% for spring, 7% for summer, and 21% for fall. Variability of outflow from the site was lower during the winter (CV=0.43) and spring (CV=0.26) than for the summer (CV=1.73) and fall (CV=1.64).

Outflow from blocks F3 (managed forest on ditched mineral soil) and F6 (managed forest on ditched organic soil) was similar for the fall and winter months, but differed in the spring and summer months (Table 3.8). Outflow from F6 was higher than outflow from F3 during the spring and summer months due to the younger age of the trees on F6. They were planted in 1992, while the trees in F3 were planted in 1983. Evapotranspiration was less from the younger trees during the high PET months of spring and summer. Outflows from blocks F3 and F6 were higher than for S4 during the higher flow and lower PET fall and winter quarters. This indicates that the seepage across the southern boundary also may have reduced the outflow from S4.

Table 3.8. Parker Tract hydrology - managed forest blocks. Quarterly and annual outflow (Q) and precipitation (P) are shown for 1996 to 1998. Soils types are: (F3) mineral; (F6) organic; (S4) mixed soils. Precipitation measurements were from R6 for F6 and S4, and from R1 for F3 (see Figure 2.7).

	Winter Quarter			*Spring Quarter*			*Summer Quarter*			*Fall Quarter*			*Annual Totals*		
Site and Year	Q mm	P mm	Q/P %	Q mm	P mm	Q/P %	Q mm	P mm	Q/P %	Q mm	P mm	Q/P %	Q mm	P mm	Q/P %
F3 Block															
1996				25	175	14%	36	561	6%	244	284	86%			
1997	196	211	93%	28	180	15%	0	307	0%	0	236	0%	224	935	24%
1998	267	368	72%	36	345	10%	0	269	0%	0	279	0%	302	1,262	24%
Average	231	290	83%	30	234	13%	12	379	2%	81	267	29%	263	1,099	24%
Std Dev	50	111	14%	5	97	3%	21	159	4%	141	27	49%	56	232	0%
CV	0.22	0.38	0.17	0.18	0.41	0.21	1.73	0.42	1.73	1.73	0.10	1.73	0.21	0.21	0.00
F6 Block															
1996				79	208	38%	206	541	38%	244	340	72%			
1997	165	218	76%	30	208	15%	0	279	0%	0	249	0%	196	955	20%
1998	292	427	68%	74	353	21%	0	218	0%	0	279	0%	366	1,278	29%
Average	229	323	72%	61	257	24%	69	346	13%	81	290	24%	281	1,116	25%
Std Dev	90	147	5%	27	84	12%	119	171	22%	141	47	41%	120	228	6%
CV	0.39	0.46	0.07	0.44	0.33	0.49	1.73	0.49	1.73	1.73	0.16	1.73	0.43	0.20	0.26
S4 Outlet															
1996	127	320	40%	43	208	21%	107	541	20%	201	340	59%	478	1,410	34%
1997	114	218	52%	25	208	12%	0	279	0%	5	249	2%	145	955	15%
1998	241	427	57%	41	353	12%	0	218	0%	3	279	1%	284	1,278	22%
Average	161	322	50%	36	257	15%	36	346	7%	69	290	21%	302	1,214	24%
Std Dev	70	104	9%	10	84	5%	62	171	11%	114	47	33%	167	234	9%
CV	0.43	0.32	0.18	0.26	0.33	0.35	1.73	0.49	1.73	1.64	0.16	1.61	0.55	0.19	0.40

Van Swamp and Pungo Lake

Annual rainfall for the Van Swamp study, located east of the Suffolk Scarp, varied from 1,020 mm/yr in 1986 to 1,566 mm/yr in 1979 (Table 3.9). The mean annual rainfall value for this period (1,296 mm) was nearly the same as the long-term average at Plymouth, N.C. (1,295 mm) (Table 3.1). Rainfall was highest for the summer months (361 mm) and lowest during the fall (250 mm) (Table 3.9). Mean rainfall was 332 mm for the spring months and 350 mm for the winter months. Average quarterly rainfall amounts were below normal for the summer, above normal for the winter and spring, and normal for the fall.

Annual rainfall during the study of the Pungo Lake site, also located east of the Suffolk Scarp, varied from 1,068 mm/yr in 1977 to 1,566 mm/yr in 1979 (Table 3.10). The mean annual rainfall value for the three-year period (1,336 mm) was slightly higher than the long-term average at Plymouth, N.C. (1,295 mm) (Table 3.1). Rainfall was highest in the spring months (408 mm). Rainfall during summer months (358 mm) was higher than in the winter months (306 mm). Average quarterly rainfall amounts were below normal for the winter and the summer, and above normal for the spring and fall.

Annual outflow for the Van Swamp watershed averaged 391 mm and ranged from 275 to 539 mm (Table 3.9). The Van Swamp watershed included a mixture of forested lands with approximately equal areas of managed stands and natural stands. The soils were a combination of mineral and organic soils. Some were ditched, and some were not. Outflow from the site was highest during winter months and lowest during the summer. During the winter quarter, average outflow was 224 mm, accounting for 62% of the average winter precipitation, and hydrologic response values for individual years ranged from 41 to 84%. Seasonal outflow varied considerably among years, ranging from 7 to 231 mm for spring, from 2 to 140 mm for summer, and from 2 to 238 mm for fall. Average

Table 3.9. Van Swamp hydrology. Quarterly and annual outflow (Q) and precipitation (P) are shown for three periods (1977 to 1979, 1985 to 1987, and 1993 to 1995).

	Winter Quarter			*Spring Quarter*			*Summer Quarter*			*Fall Quarter*			*Annual Totals*		
Year	**Q** *mm*	**P** *mm*	**Q/P** *%*	**Q** *mm*	**P** *mm*	**Q/P** *%*	**Q** *mm*	**P** *mm*	**Q/P** *%*	**Q** *mm*	**P** *mm*	**Q/P** *%*	**Q** *mm*	**P** *mm*	**Q/P** *%*
1977				82	298	27%	47	345	14%	238	276	86%			
1978	305	362	84%	231	459	50%	2	327	0%	2	225	1%	539	1,373	39%
1979	242	419	58%	193	564	34%	17	354	5%	65	230	28%	517	1,566	33%
1985	124	237	52%	7	159	4%	19	459	4%	150	303	49%	299	1,158	26%
1986	77	187	41%	36	194	19%	140	450	31%	22	190	12%	275	1,020	27%
1987	282	402	70%	122	292	42%	43	460	9%	23	176	13%	470	1,330	35%
1993	296	417	71%	97	304	32%	3	193	2%	8	281	3%	404	1,195	34%
1994	200	404	50%	51	320	16%	6	369	2%	23	245	9%	280	1,337	21%
1995	263	372	71%	50	399	13%	12	297	4%	17	321	5%	342	1,389	25%
Average	224	350	62%	96	332	26%	32	361	8%	61	250	23%	391	1,296	30%
Std Dev	84	88	14%	74	126	15%	44	87	10%	81	49	28%	107	167	6%
CV	0.37	0.25	0.23	0.77	0.38	0.56	1.36	0.24	1.22	1.33	0.20	1.23	0.28	0.13	0.21

hydrologic response was 26% for spring, 8% for summer, and 23% for fall. Variability of outflow from the site was least during the winter quarter (CV=0.37) compared to the spring (CV=0.77), summer (CV=1.36), and fall (CV=1.33).

Annual outflow for the Pungo Lake site (a natural forest on unditched organic soil) averaged 483 mm and ranged from 314 to 571 mm (Table 3.10). Outflow from the site was highest during winter months and lowest during the summer. During the winter quarter, average outflow was 227 mm, accounting for 82% of the average winter precipitation, and hydrologic response values for individual years ranged from 48 to 104%. Outflow in spring and fall varied considerably among years, ranging from 38 to 228 mm for spring and from 2 to 191 mm for fall. Average hydrologic response was 38% for spring and 19% for fall. Outflow was very low for the summer months, averaging 13 mm, since rainfall for all of the summer periods was below average. Variability of outflow from the site was least during the winter quarter (CV=0.44) compared to the spring (CV=0.63), summer (CV=0.82), and fall (CV=1.61).

Summary of Hydrology

The field studies summarized in this report varied in duration and were conducted over different periods of time from 1976 to 2000. One confounding factor in comparing the data is differing weather patterns. While some interannual variation exists across the regional study area in long-term annual rainfall (13 to 17%) and PET (6 to 8%), interannual variations on a quarterly basis are larger at 26 to 38% and 9 to 29%, respectively (see Table 3.1). That is, extended wet periods and extended dry periods usually occur over 2 to 3

Table 3.10. Pungo Lake hydrology. Quarterly and annual outflow (Q) and precipitation (P) are shown for 1976 to 1979.

	Winter Quarter			*Spring Quarter*			*Summer Quarter*			*Fall Quarter*			*Annual Totals*		
Year	**Q** *mm*	**P** *mm*	**Q/P** *%*	**Q** *mm*	**P** *mm*	**Q/P** *%*	**Q** *mm*	**P** *mm*	**Q/P** *%*	**Q** *mm*	**P** *mm*	**Q/P** *%*	**Q** *mm*	**P** *mm*	**Q/P** *%*
1976				38	298	13%	28	406	7%	24	505	5%			
1977	142	137	104%	228	310	74%	4	345	1%	191	276	69%	565	1,068	53%
1978	338	362	94%	218	459	47%	13	327	4%	2	225	1%	571	1,373	42%
1979	200	419	48%	100	564	18%	8	354	2%	7	230	3%	314	1,566	20%
Average	227	306	82%	146	408	38%	13	358	4%	56	309	19%	483	1,336	38%
Std Dev	101	149	30%	93	128	28%	11	34	3%	90	133	33%	147	251	17%
CV	0.44	0.49	0.37	0.63	0.31	0.75	0.82	0.10	0.72	1.61	0.43	1.70	0.30	0.19	0.44

months, while weather patterns averaged over a 12-month period are less variable. Because of these year-to-year variations in seasonal weather patterns, accurately characterizing seasonal variations in outflow volumes and nutrient export amounts requires monitoring of forest outflow over a decade or longer rather than a few years. While some of the studies reported here nearly approach that length, most field studies are usually limited to three or four years. Seasonal patterns derived from the studies conducted over a few years are best interpreted in the context of weather patterns observed during the study, which may not reflect long-term average conditions.

The outflow and hydrologic response data showed a consistent seasonal pattern across sites (Table 3.11 and Figs. 3.1 and 3.2). For all of the sites studied, the season with the highest outflow and hydrologic response was winter (Table 3.11). The forest sites reviewed in this study essentially acted as reservoirs, with rainfall as the only input and ET and outflow as the predominant water losses. Vertical seepage to underlying aquifers was another possible water loss; however, deep seepage has been estimated to be less than 12 mm in the Albemarle-Pamlico region (Heath, 1975), which is negligible compared to other losses. Another possible source of loss is lateral seepage to adjacent drained areas, which was usually not quantified and could account for some of the variation in measured annual outflows. Outflow from the sites was therefore mostly dependent on the amounts and variations of the rainfall and ET (Table 3.1). Indeed, the median of mean annual hydrologic response among the sites was 31% with an interquartile range of 26 to 35% (Fig. 3.2), which is consistent with the annual average ratio of excess water (P-PET) to rainfall (P) for the regional weather stations (Table 3.1). Long-term estimates of excess water derived from regional weather station data ranged from 29% at New Bern to 30% at Morehead City and Plymouth. For most of the forested conditions reviewed in this report we can assume that actual ET is nearly equal to PET.

Deviations from regionally averaged ET and the assumption of negligible seepage may explain much of the variation in annual outflows and hydrologic response. Sites that had higher values for mean annual hydrologic response (43% for T104 and 45% for T107) had scrubby vegetation and reduced ET. Sites that had lower values for hydrologic response (24% for S4, 15% for UD, and 17% for W1) had possible lateral seepage losses or lower

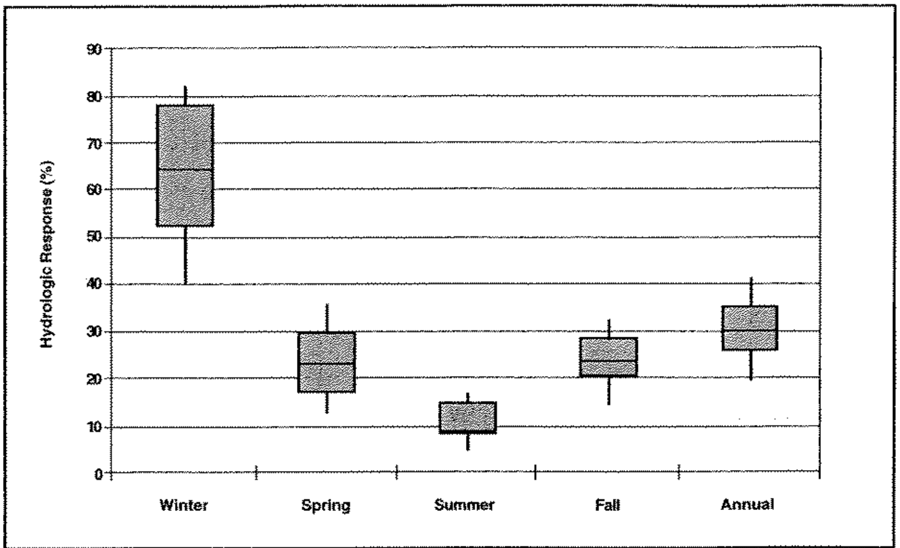


Figure 3.2. Distribution of mean seasonal and annual hydrologic response for all sites. The box and wisker plots show values for 10th, 25th, 50th, 75th, and 90th percentile rankings.

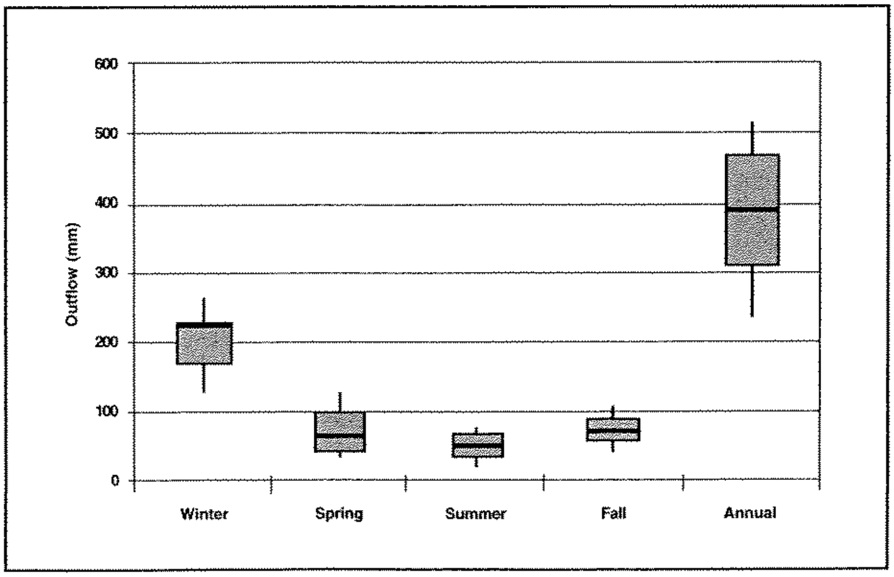


Figure 3.1. Distribution of mean seasonal and annual outflow for all sites. The box and wisker plots show values for 10th, 25th, 50th, 75th, and 90th percentile rankings.

Table 3.11. Mean seasonal and annual outflow and hydrologic response by site.

Study Site	Block / Outlet	Winter	Spring	Summer	Fall	Annual
Mean Outflow (mm)						
Carteret 7	D1	249	54	50	109	462
Isaac Creek	B	113	47	79	88	327
Isaac Creek	ABC	175	65	75	110	424
Isaac Creek	D	170	52	88	74	384
Isaac Creek	UD	87	23	40	36	194
Jones County	J2&J3	296	102	50	60	475
Tyrrell County	T102	221	108	29	51	408
Tyrrell County	T104	224	146	68	102	538
Tyrrell County	T107	274	99	55	124	553
Washington County	W1	153	37	46	1	205
Parker Tract	F3	231	30	12	81	277
Parker Tract	F6	229	61	69	81	363
Parker Tract	S4	161	36	36	69	302
Van Swamp	VANS	224	96	32	61	391
Pungo Lake	PL	227	146	13	56	483
Hydrologic Response (%)						
Carteret 7	D1	63%	19%	8%	29%	30%
Isaac Creek	B	36%	18%	17%	29%	25%
Isaac Creek	ABC	55%	25%	16%	36%	33%
Isaac Creek	D	54%	22%	18%	25%	31%
Isaac Creek	UD	28%	9%	8%	11%	15%
Jones County	J2&J3	78%	32%	11%	24%	37%
Tyrrell County	T102	78%	30%	8%	19%	33%
Tyrrell County	T104	79%	44%	19%	28%	43%
Tyrrell County	T107	95%	30%	14%	35%	45%
Washington County	W1	46%	11%	9%	1%	17%
Parker Tract	F3	83%	13%	2%	29%	26%
Parker Tract	F6	72%	24%	13%	24%	33%
Parker Tract	S4	50%	15%	7%	21%	24%
Van Swamp	VANS	62%	26%	8%	23%	30%
Pungo Lake	PL	82%	38%	4%	19%	38%

rainfall amounts during the study period. Individual sites with low or high values for annual hydrologic response typically had low or high values, respectively, for individual seasons (Table 3.11).

Seasonal variations in outflow from the sites logically followed the seasonal variations in rainfall and PET observed at the nearby weather stations (Table 3.1). Most of the outflow occurred during the winter months at all sites (Table 3.11; Fig. 3.3) when PET was low and excess water was highest (Table 3.11). At least 75 mm of outflow occurred for every winter quarter at every site, and outflow exceeded 208 mm for half of the 84 winter quarters studied (Table 3.12). Outflow occurred in 86 out of 90 spring quarters aggregated across sites (Fig. 3.3) despite average spring PET exceeding rainfall by about 30 mm (Table 3.1). This relatively consistent occurrence of spring outflow was due to the consistently wet conditions from the winter before. Spring outflow was less than winter outflow, with over half of the spring quarters resulting in less than 58 mm of outflow (Table 3.12) and only four spring quarters resulting in greater than 210 mm of outflow. Outflow at the beginning of the summer quarter was typically low due to frequent low outflow in late spring and high ET. No outflow occurred for 25% of the summer quarters; however, high rainfall in other summer quarters, associated with convective and tropical storms, produced more than 250 mm of outflow in three summer quarters (Fig. 3.3). The effect of this year-to-year variation in summer rainfall carried over into the fall quarter, with no outflow in 17% of fall quarters and more than 250 mm of outflow in five others (Fig. 3.3). Since ET was low for the fall quarters and rainfall always exceeded ET (Table 3.1), soil water recharge had usually occurred by the end of the fall quarter. A

Table 3.12. Distribution of total quarterly outflow volumes for site years (see Fig. 3.3). Values are based on all available site years (winter, N=84; spring, N=90; summer, N=91; and fall, N=90).

Percent of site years	Winter	Spring	Summer	Fall
	Quarterly Outflow Volume (mm)			
10th Percentile	114.4	14.9	0.0	0.0
25th Percentile	144.7	29.5	2.0	5.1
Median	208.3	58.4	35.6	45.4
75th Percentile	282.1	117.2	110.8	124.7
90th Percentile	310.8	166.7	149.9	242.4

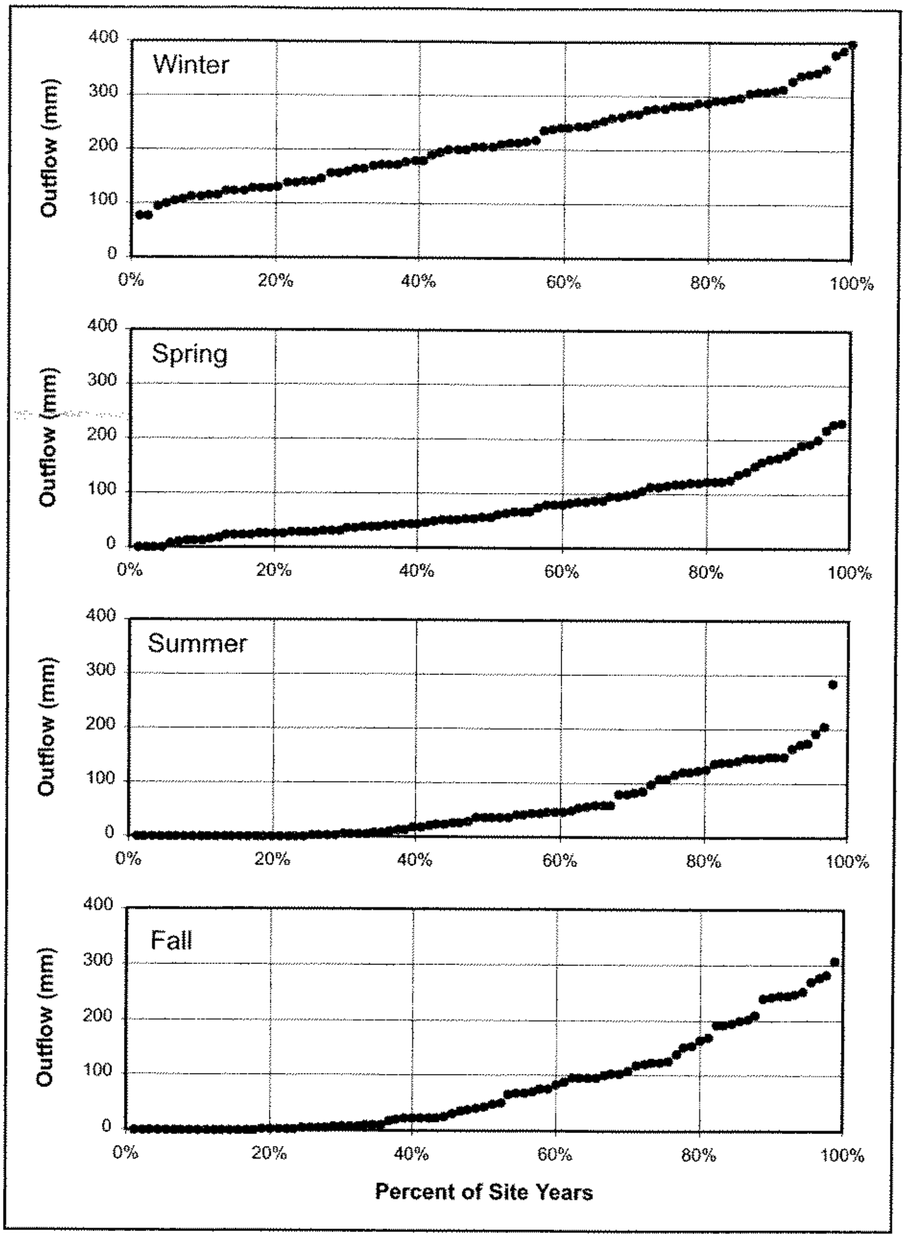


Figure 3.3. Distribution of total quarterly outflow volumes ranked in ascending order for all site years. Plots include data from all site years (winter, N=84; spring, N=90; summer, N=91; and fall, N=90).

relatively high water table and wet soil moisture conditions existed at the beginning of the winter quarters, resulting in high hydrologic response to winter precipitation.

Differences in seasonal and annual outflow were not distinguishable for the different site characteristics except where smaller vegetation reduced ET, resulting in more outflow. While differences due to most changes in site characteristics could not be distinguished, some general statements about seasonal and annual outflow from forested lands in eastern North Carolina can be made based on these studies. On average, about 30% of annual rainfall will drain from forested sites (Fig. 3.2). Most of this outflow will occur in the winter quarter when about 40 to 80% of winter rainfall flows to headwater streams. This winter outflow period will occur with only moderate variation among years. High outflows may also occur during spring, summer, and fall seasons in some years, but average values across years are much lower than in the winter period. In fact, summer and fall seasons for many site years had extremely low outflow (Fig. 3.3). The high variability in summer and fall outflow is due to infrequent large tropical storms that affect outflow in some years.

SECTION 4 - NUTRIENT CONCENTRATIONS

The nutrient data summarized in this chapter and used in the rest of this report are from field studies of varying sampling intensities. Results from two types of studies are reported: results from high-frequency sampling studies (Carteret 7, Parker Tract, Washington County, Jones County, and Tyrrell County) and results from monitoring studies (Isaac Creek, Van Swamp, Pungo Lake, Croatan/Craven 40, Open Grounds Farm, and the multi-tract study). Water quality sampling occurred at least once a week for the high-frequency studies; some of the samples were collected as flow-proportional composite samples or as grab samples during high-flow events. Sampling for the monitoring studies occurred at biweekly to monthly intervals.

Concentrations of nutrients in outflow from any watershed vary with time. The variability of a constituent can be affected by the size of a watershed, the flashiness of a watershed, the type of constituent, and the processes involved in transport and transformation of the constituent (Richards and Holloway, 1987). Variability generally increases with decreasing watershed size and with increasing flashiness. Since nutrient concentrations are variable, the accuracy of quantifying nutrient characteristics from a finite number of samples depends on the frequency of sample collection. Studies have shown that the accuracy of calculating constituent export load from a watershed using sampled concentrations declines as sampling becomes less frequent than once a week (Richards and Holloway, 1987; Preston et al., 1989; and Robertson and Roerish, 1999). Nutrient concentrations and export values reported for the high-frequency sampling sites reported here, therefore, can be considered accurate. While nutrient concentration and export values reported for the less frequently sampled monitoring studies are possibly less accurate, they can still be used to support the trends observed in the high-frequency sampling studies.

Carteret County - Carteret 7

Mean nutrient concentrations in outflow from the D1 block (managed forest on ditched mineral soil) varied seasonally (Table 4.1). Dissolved inorganic N (DIN, NO_3-N + NH_4-N) was highest at 0.61 mg/L during the winter and spring quarters when most of the annual outflow from the site occurs, with NO_3-N accounting for more than 95% of DIN. In contrast, organic N (Org-N, TKN less NH_4-N) was highest during the summer and fall at 0.56 and 0.57 mg/L compared with mean seasonal concentrations of 0.35 and 0.37 mg/L during the winter and spring. The result of these off-setting trends in nitrogen concentrations is that TN was relatively constant throughout the year, with mean seasonal concentrations ranging from 0.96 mg/L in the winter to 1.06 mg/L in the summer. Based on a simple comparison of overall mean concentrations for the entire study period, NO_3-N contributed approximately 56% of TN while the remainder was contributed by organic fractions; NH_4-N contributed less than 1% of TN. Total P (TP) concentration in outflow from D1 ranged from 0.013 mg/L in the summer to 0.064 mg/L in the spring.

Comparisons of nutrient concentrations for all three watersheds for the pre-treatment calibration period indicate mean concentrations of nutrients for D1 are not representative of D2 and D3. Amatya et al. (1998) and Smith (1994) evaluated water quality characteristics of the three watersheds and concluded that there were statistically significant differences in concentrations of NO_3-N, TKN, and TN. Mean concentrations of NO_3-N and TKN (and thus TN) for D2 and D3 were 36 to 75% lower than the

Table 4.1. Mean nutrient concentrations (mg/L) in outflow by quarter for the Carteret 7 D1 watershed.

Site	*Parameter*	*Statistic*	*Winter*	*Spring*	*Summer*	*Fall*
D1	NO_3-N	Mean	0.60	0.58	0.48	0.45
		Std Dev	0.06	0.18	0.15	0.12
		CV	0.11	0.30	0.31	0.27
D1	NH_4-N	Mean	0.009	0.029	0.017	0.007
		Std Dev	0.004	0.012	0.005	0.003
		CV	0.44	0.41	0.29	0.43
D1	DIN	Mean	0.61	0.61	0.50	0.46
D1	Org-N	Mean	0.35	0.37	0.56	0.57
D1	Total N	Mean	0.96	0.98	1.06	1.03
		Std Dev	0.07	0.21	0.31	0.25
		CV	0.08	0.21	0.29	0.24
D1	Total P	Mean	0.048	0.064	0.013	0.032
		Std Dev	0.010	0.027	0.003	0.009
		CV	0.21	0.42	0.23	0.28

Table 4.2. Mean nutrient concentrations (mg/L) in outflow by quarter for the Isaac Creek watershed. Data are shown for drainage from managed forest blocks.

Site	*Parameter*	*Statistic*	*Winter*	*Spring*	*Summer*	*Fall*
Block B	NO_3-N	Mean	0.031	0.017	0.021	0.013
		Std Dev	0.032	0.009	0.015	0.006
		CV	1.03	0.53	0.71	0.46
Block B	NH_4-N	Mean	0.091	0.062	0.071	0.029
		Std Dev	0.037	0.078	0.071	0.030
		CV	0.41	1.26	1.00	1.03
Block B	DIN	Mean	0.12	0.08	0.09	0.04
Block B	Org-N	Mean	0.81	0.66	0.75	0.58
Block B	Total N	Mean	0.93	0.74	0.84	0.62
		Std Dev	0.28	0.24	0.22	0.30
		CV	0.30	0.32	0.26	0.48
Block B	Total P	Mean	0.063	0.095	0.071	0.096
		Std Dev	0.032	0.062	0.027	0.059
		CV	0.51	0.65	0.38	0.61
ABC Outlet	NO_3-N	Mean	0.04	0.01	0.02	0.03
		Std Dev	0.05	0.01	0.02	0.04
		CV	1.15	0.92	1.14	1.33
ABC Outlet	NH_4-N	Mean	0.06	0.04	0.05	0.08
		Std Dev	0.05	0.05	0.04	0.16
		CV	0.78	1.18	0.78	2.06
ABC Outlet	DIN	Mean	0.10	0.05	0.07	0.11
ABC Outlet	Org-N	Mean	0.56	0.51	0.68	0.37
ABC Outlet	Total N	Mean	0.66	0.56	0.75	0.48
		Std Dev	0.25	0.13	0.20	0.17
		CV	0.38	0.23	0.27	0.35
ABC Outlet	Total P	Mean	0.086	0.090	0.064	0.084
		Std Dev	0.062	0.086	0.021	0.071
		CV	0.72	0.96	0.33	0.85
D Outlet	NO_3-N	Mean	0.034	0.030	0.032	0.031
		Std Dev	0.040	0.026	0.056	0.049
		CV	1.18	0.87	1.75	1.58
D Outlet	NH_4-N	Mean	0.037	0.061	0.025	0.016
		Std Dev	0.036	0.132	0.030	0.013
		CV	0.97	2.16	1.20	0.81
D Outlet	DIN	Mean	0.07	0.09	0.06	0.05
D Outlet	Org-N	Mean	0.42	0.59	0.64	0.47
D Outlet	Total N	Mean	0.49	0.68	0.70	0.52
		Std Dev	0.19	0.22	0.22	0.30
		CV	0.39	0.32	0.31	0.58
D Outlet	Total P	Mean	0.023	0.079	0.063	0.060
		Std Dev	0.016	0.087	0.019	0.042
		CV	0.70	1.10	0.30	0.70

corresponding value for D1 for the same period. In these comparisons, values were used for the period in which all three watersheds were under conventional drainage (i.e., 1.0 m weir depth). Observations of lower concentrations at D2 and D3 indicate that the average NO_3-N and TKN concentrations are lower for the watershed taken collectively than those reported in Table 4.1.

Carteret County - Isaac Creek

Mean concentrations of DIN in outflows from the three managed forest sites were generally low, with NO_3-N and NH_4-N concentrations typically less than 0.1 mg/L for block B (organic soils), block D (mostly mineral soils), and the ABC outlet draining a mixture of organic and mineral soils (Table 4.2). NH4-N accounted for a majority of DIN from blocks B and ABC, 76% and 63%, respectively, but only about 50% of DIN from block D. Total N (TN) concentration averages at the three sites varied between 0.6 and 0.8 mg/L, with the lowest seasonal values in the fall or winter depending on the site. Overall, Org-N fractions contributed a majority of TN in the outflow from the managed pine stands (87 to 90%) and was highest during the summer at the D and ABC outlets. The mean concentration of TP in outflows among years was higher for the ABC outlet (0.08 mg/L) than for block B (0.06) and the D outlet (0.06 mg/L) along the northern slope.

Mean nutrient concentrations among years at the unditched natural stand on organic soils (UD) had a seasonal pattern similar to those described above for the managed pine stands (Table 4.3). For the two monitoring periods (1985 to 1988 and 1995 to 1996), the DIN concentrations varied seasonally, with the highest concentrations occurring in the spring. Overall, DIN accounted for 12% of the nitrogen in the outflow, with NH_4-N accounting for an average of 88% of DIN. More than 80% of TN occurred as particulate and dissolved fractions of Org-N. TP concentrations were approximately 0.04 to 0.05 mg/L for all seasons, which is similar to those from the D outlet. Thus, a general comparison of outflow water quality for block UD and the managed pine stands within the Isaac Creek watershed indicate similar characteristics for both settings, with higher mean concentrations of TN from the unditched natural stand on organic

Table 4.3. Mean nutrient concentrations (mg/L) in outflow by quarter for Block UD at the Isaac Creek study site.

Period	Parameter	Statistic	Winter	Spring	Summer	Fall
1985-88	NO_3-N	Mean	0.017	0.010	0.020	0.010
		Std Dev	0.008	0.003	0.014	0.002
		CV	0.47	0.30	0.70	0.20
1985-88	NH_4-N	Mean	0.114	0.193	0.066	0.024
		Std Dev	0.077	0.201	0.040	0.017
		CV	0.68	1.04	0.61	0.71
1985-88	DIN	Mean	0.13	0.20	0.09	0.03
1985-88	Org-N	Mean	1.11	1.05	1.19	0.87
1985-88	Total N	Mean	1.24	1.25	1.28	0.90
		Std Dev	0.18	0.15	0.14	0.25
		CV	0.15	0.12	0.11	0.28
1985-88	Total P	Mean	0.043	0.066	0.051	0.028
		Std Dev	0.038	0.043	0.021	0.016
		CV	0.88	0.65	0.41	0.57
1995-96	NO_3-N	Mean	0.024	0.023	0.024	0.028
		Std Dev	0.007	0.020	0.010	0.025
		CV	0.29	0.87	0.42	0.89
1995-96	NH_4-N	Mean	0.025	0.256	0.046	0.044
		Std Dev	0.020	0.396	0.033	0.024
		CV	0.80	1.55	0.72	0.55
1995-96	DIN	Mean	0.05	0.28	0.07	0.07
1995-96	Org-N	Mean	1.08	1.08	1.42	1.25
1995-96	Total N	Mean	1.13	1.36	1.49	1.32
		Std Dev	0.25	0.36	0.26	0.14
		CV	0.22	0.26	0.17	0.11
1995-96	Total P	Mean	0.035	0.037	0.037	0.050
		Std Dev	0.008	0.015	0.006	0.023
		CV	0.23	0.41	0.16	0.46

soils mainly as Org-N. This suggests that the depth of drainage—shallow from UD and deeper from the managed forest blocks—was not a dominant factor in nutrient concentrations.

Jones County - Jones 5

Mean concentration of total N in the outflow from the Jones 5 block (managed forest on ditched mineral soil) among years was 0.67 mg/L on an annual basis. TN concentrations varied between 0.56 and 0.78 among seasons, with the highest concentrations occurring in the summer and fall (Table 4.4). Organic N, which averaged 0.50 mg/L, was the dominant form of TN in outflow and accounted for 71 to 90% of TN (average = 78%) depending on season. The overall concentration of Org-N also varied by season, with the highest average concentration occurring in the summer quarter. Seasonal variation in DIN concentrations was greater than for Org-N but differed in timing; maximum DIN concentrations (0.22 to 0.27 mg/L) occurred during fall and winter quarters when trees are typically dormant. For all seasons, NH_4-N accounted for a majority of DIN. Mean TP concentrations averaged between 0.023 and 0.028 mg/L for the fall through spring quarters, but the highest average concentration occurred during the summer (0.043 mg/L).

Tyrrell County

Mean concentrations of DIN in outflow from the natural blocks sampled in Tyrrell County were generally low among years, particularly in outflow from the organic soil sites (T104 and T107, Table 4.5). For the sites on organic soils, NO_3-N and NH_4-N concentrations were typically less than 0.1 mg/L compared to 0.05 to 0.41 mg/L for the mineral soil site (T102). Since the detection limit (DL) of NH_4-N for that study was 0.1 mg/L, vs. a DL of 0.01 mg/L for NO_3-N, NH_4-N concentrations reported as less than 0.1 mg/L were replaced with a value of 0.05 mg/L to allow estimation of mean values. Consequently, small differences in NH_4-N and DIN concentration from the study should be interpreted cautiously. For the shallow organic soil site (T107), NH_4-N values above the DL were not available, so a meaningful mean concentration could not be calculated. Seasonally, TN concentration at the three sites varied between 0.9 and 1.8 mg/L, with the exception of a value of 0.7 mg/L in outflow from the mineral soil during winter months. The annual TN concentrations for these sites were nearly the same, averaging 1.22 mg/L.

Table 4.4. Mean nutrient concentrations (mg/L) in outflow by quarter for the Jones 5 study site. Values are the average for blocks J2 and J3 based on quarterly flow-weighted concentrations by block.

Site	Parameter	Statistic	Winter	Spring	Summer	Fall
J2&J3	NO_3-N	Mean	0.040	0.009	0.022	0.009
J2&J3	NH_4-N	Mean	0.23	0.04	0.08	0.21
J2&J3	DIN	Mean	0.27	0.05	0.10	0.22
J2&J3	Org-N	Mean	0.36	0.51	0.62	0.57
J2&J3	Total N	Mean	0.63	0.56	0.72	0.78
J2&J3	Total P	Mean	0.024	0.023	0.043	0.028

Table 4.5. Mean nutrient concentrations (mg/L) in outflow by quarter for the Tyrrell County study sites. Soil types are: (T102) mineral; (T104) deep organic; and (T107) shallow organic.

Site	*Parameter*	*Statistic*	*Winter*	*Spring*	*Summer*	*Fall*
T102	NO_3-N	Mean	0.076	0.060	0.110	0.240
		Std Dev	0.104	0.052	0.170	0.410
		CV	1.37	0.87	1.55	1.71
T102	NH_4-N	Mean	0.060	0.060	0.180	0.120
		Std Dev	0.050	0.050	0.300	0.280
		CV	0.83	0.83	1.67	2.33
T102	DIN	Mean	0.14	0.12	0.29	0.36
T102	Org-N	Mean	0.59	0.85	1.61	0.91
T102	Total N	Mean	0.690	1.170	1.770	1.190
		Std Dev	0.260	0.740	0.860	1.030
		CV	0.38	0.63	0.49	0.87
T102	Total P	Mean	0.025	0.043	0.066	0.100
		Std Dev	0.031	0.041	0.042	0.170
		CV	1.24	0.95	0.64	1.70
T104	NO_3-N	Mean	0.052	0.016	0.020	0.021
		Std Dev	0.098	0.023	0.037	0.028
		CV	1.88	1.44	1.85	1.33
T104	NH_4-N	Mean	0.068	0.110	0.076	0.068
		Std Dev	0.055	0.160	0.082	0.069
		CV	0.81	1.45	1.08	1.01
T104	DIN	Mean	0.12	0.13	0.10	0.09
T104	Org-N	Mean	0.98	0.96	1.50	1.27
T104	Total N	Mean	1.100	1.090	1.600	1.360
		Std Dev	0.380	0.400	0.840	0.440
		CV	0.35	0.37	0.53	0.32
T104	Total P	Mean	0.044	0.051	0.120	0.044
		Std Dev	0.044	0.044	0.170	0.025
		CV	1.00	0.86	1.42	0.57
T107	NO_3-N	Mean	0.035	0.042	0.034	0.052
		Std Dev	0.070	0.063	0.077	0.049
		CV	2.00	1.50	2.26	0.94
T107	NH_4-N	Mean				
		Std Dev				
		CV				
T107	DIN	Mean	0.04	0.04	0.03	0.05
T107	Org-N	Mean	0.91	0.98	1.40	1.23
T107	Total N	Mean	0.940	1.020	1.430	1.280
		Std Dev	0.420	0.480	0.520	0.680
		CV	0.45	0.47	0.36	0.53
T107	Total P	Mean	0.050	0.021	0.079	0.021
		Std Dev	0.073	0.020	0.082	0.014
		CV	1.46	0.95	1.04 *	0.67

Organic N fractions contributed a majority of TN at all sites; Org-N contributed more than 90% of TN concentration at the organic soil sites and about 80% at the mineral site. On a seasonal basis, Org-N was highest for the summer season for all sites. TP concentrations were similar among sites, ranging seasonally from 0.02 to 0.12 mg/L.

Washington County

Large seasonal variations in mean TN concentrations in outflow among years were observed at the natural forested site on unditched mineral soil in

Table 4.6. Mean nutrient concentrations (mg/L) in outflow by quarter for W1 at the Washington County study site.

Site	*Parameter*	*Statistic*	*Winter*	*Spring*	*Summer*	*Fall*
W1	NO_3-N	Mean	0.140	0.008	0.157	0.076
		Std Dev	0.497	0.032	0.491	0.283
		CV	3.55	4.00	3.13	3.72
W1	NH_4-N	Mean	0.090	0.195	0.269	0.074
		Std Dev	0.062	0.127	0.121	0.073
		CV	0.69	0.65	0.45	0.99
W1	DIN	Mean	0.23	0.20	0.43	0.15
W1	Org-N	Mean	0.59	1.06	1.09	0.64
W1	Total N	Mean	0.82	1.26	1.52	0.79
		Std Dev	0.63	0.47	0.64	0.37
		CV	0.77	0.37	0.42	0.47
W1	Total P	Mean	0.046	0.063	0.045	0.018
		Std Dev	0.060	0.065	0.038	0.027
		CV	1.30	1.03	0.84	1.50

Table 4.7. Mean nutrient concentrations (mg/L) in outflow by quarter for the Parker Tract study site. The organic content of soils increases according to F1<F3<F8<F6<F5 for managed pine blocks. Blocks F4 and F7 have natural vegetation.

Site	*Parameter*	*Statistic*	*Winter*	*Spring*	*Summer*	*Fall*
F1	NO_3-N	Mean	0.10	0.07	0.17	0.20
		Std Dev	0.09	0.12	0.29	0.29
		CV	0.89	1.61	1.73	1.46
F1	NH_4-N	Mean	0.041	0.062	0.033	0.080
		Std Dev	0.049	0.089	0.058	0.045
		CV	1.20	1.44	1.76	0.56
F1	DIN	Mean	0.14	0.14	0.20	0.28
F1	Org-N	Mean	0.36	0.48	0.67	0.24
F1	Total N	Mean	0.50	0.62	0.87	0.52
		Std Dev	0.21	0.18	0.31	0.52
		CV	0.43	0.29	0.35	0.99
F1	Total P	Mean	0.012	0.020	0.017	0.016
		Std Dev	0.008	0.011	0.006	0.005
		CV	0.67	0.55	0.35	0.31
F3	NO_3-N	Mean	1.24	0.95	3.43	1.69
		Std Dev	0.82	1.23	0.50	1.37
		CV	0.66	1.30	0.15	0.81
F3	NH_4-N	Mean	0.22	0.23	0.43	0.18
		Std Dev	0.14	0.22	0.35	0.16
		CV	0.65	0.94	0.81	0.90
F3	DIN	Mean	1.46	1.18	3.87	1.86
F3	Org-N	Mean	0.36	0.47	0.80	0.59
F3	Total N	Mean	1.82	1.65	4.67	2.46
		Std Dev	0.94	1.22	0.45	1.54
		CV	0.51	0.74	0.10	0.62
F3	Total P	Mean	0.020	0.017	0.020	0.015
		Std Dev	0.010	0.006	0.000	0.005
		CV	0.50	0.35	0.00	0.33

(Table continued on next page)

Washington County. TN concentrations during the spring (1.26 mg/L) and summer (1.52 mg/L) were higher than those for fall and winter (0.79 to 0.82 mg/L) (Table 4.6). The Org-N fractions account for the majority (72 to 84%) of TN during all seasons. Contributions of NH_4-N and NO_3-N to the smaller DIN pool, which average about 20% of TN, varied by season largely due to variations in NH_4-N concentrations; NH_4-N accounted for 63 to 96% of DIN during the spring and summer months compared with 39 to 49% during fall and winter months. Seasonal average TP concentrations were relatively constant at 0.04 to 0.06 mg/L during winter to summer but extremely low (0.02 mg/L) during the fall when flow was extremely low (see Table 3.7).

Parker Tract

The mean TN concentration in outflow among years from the different forest blocks at the Parker Tract study site depended on soil type (Table 4.7). For the block with the most mineral soils (F1), the TN concentration in drainage water ranged from 0.50 mg/L to 0.87 mg/L depending on season, which is similar to values reported for mineral soils in other studies reviewed here. The mean

TN concentration in outflow from other blocks with mineral soils at the site increased as the organic content of the soils increased (seasonal averages ranged from 1.1 to 2.8 mg/L for F8 and 1.6 to 4.7 mg/L for F3). For the organic soils at the site, drainage waters had very high TN concentrations; the highest seasonal averages occurred in drainage from F6 (4.3 to 6.9 mg/L) and F5 (5.3 to 12.3 mg/L). The two blocks with natural vegetation on organic soil (F4 and F7) had lower TN concentrations than those from F5 and F6 (3.3 to 5.6 and 3.5 to 5.3 mg/L for F4 and F7, respectively), but these concentrations were three to five times higher than TN concentrations from other studies. Mean seasonal TN concentrations of the water draining to the S4 outlet from the tract, which drained one-third mineral soils and two-thirds organic soils, ranged from 3.7 mg/L in spring to 5.2 mg/L in the summer. With the exception of the F4 and F7 natural blocks, the TN concentration in drainage from the different study blocks was highest during the summer.

The soil type at the Parker Tract study site also affected the distribution of the TN between DIN and Org-N fractions (Table 4.7). Mean seasonal Org-N concentrations in the drainage water were generally less than 1 mg/L for blocks with the mineral soils compared with 2.2 to 4.5 mg/L in drainage from the organic soil blocks. The TN concentration in drainage from organic soils did not appear to be affected by vegetation type; there was a similar range in season averages for drainage from blocks with natural vegetation and managed pine plantation. However, mean seasonal DIN concentrations in drainage from organic soil blocks with pine plantation (1.0 to 9.6 mg/L) were higher than those with natural vegetation (0.6 to 2.1 mg/L). Overall, the mean seasonal DIN concentrations in the drainage water increased as the organic matter in the soils increased. For example, the DIN

Table 4.7. Mean nutrient concentrations (mg/L) in outflow by quarter for the Parker Tract study site (continued).

Site	*Parameter*	*Statistic*	*Winter*	*Spring*	*Summer*	*Fall*
F8	NO_3-N	Mean	0.44	1.03	1.40	0.40
		Std Dev	0.57	0.64	0.37	0.49
		CV	1.28	0.62	0.26	1.23
F8	NH_4-N	Mean	0.189	0.053	0.075	0.100
		Std Dev	0.125	0.056	0.050	0.067
		CV	0.66	1.06	0.67	0.67
F8	DIN	Mean	0.63	1.08	1.48	0.50
F8	Org-N	Mean	0.45	0.67	1.35	0.59
F8	Total N	Mean	1.08	1.75	2.83	1.09
		Std Dev	0.68	0.79	0.31	0.61
		CV	0.63	0.45	0.11	0.56
F8	Total P	Mean	0.016	0.010	0.023	0.017
		Std Dev	0.009	0.000	0.005	0.007
		CV	0.56	0.00	0.22	0.41
F6	NO_3-N	Mean	2.54	0.70	2.10	2.07
		Std Dev	1.24	1.38	2.97	2.53
		CV	0.49	1.98	1.42	1.22
F6	NH_4-N	Mean	0.18	0.27	0.30	0.23
		Std Dev	0.23	0.17	0.26	0.10
		CV	1.31	0.61	0.85	0.41
F6	DIN	Mean	2.72	0.97	2.40	2.30
F6	Org-N	Mean	3.26	3.36	4.50	3.71
F6	Total N	Mean	5.98	4.33	6.90	6.01
		Std Dev	1.35	1.42	3.56	2.69
		CV	0.23	0.33	0.52	0.45
F6	Total P	Mean	0.055	0.093	0.110	0.119
		Std Dev	0.019	0.023	0.042	0.076
		CV	0.35	0.25	0.38	0.64
F5	NO_3-N	Mean	2.82	3.80	8.80	2.93
		Std Dev	2.45	4.28	5.12	3.17
		CV	0.87	1.13	0.58	1.08
F5	NH_4-N	Mean	0.29	0.28	0.77	0.38
		Std Dev	0.24	0.29	0.42	0.28
		CV	0.82	1.01	0.54	0.72
F5	DIN	Mean	3.11	4.08	9.57	3.31
F5	Org-N	Mean	2.15	2.19	2.70	2.40
F5	Total N	Mean	5.26	6.27	12.3	5.71
		Std Dev	2.43	4.26	4.91	3.37
		CV	0.46	0.68	0.40	0.59
F5	Total P	Mean	0.026	0.027	0.020	0.029
		Std Dev	0.011	0.015	0.000	0.018
		CV	0.42	0.56	0.00	0.62
S4 Outlet	NO_3-N	Mean	2.98	0.67	1.69	1.62
		Std Dev	1.94	1.19	1.92	2.04
		CV	0.65	1.77	1.14	1.26
S4 Outlet	NH_4-N	Mean	0.21	0.82	0.73	0.19
		Std Dev	0.11	0.49	0.49	0.15
		CV	0.53	0.60	0.68	0.79
S4 Outlet	DIN	Mean	3.19	1.49	2.42	1.81

(Table continued on next page)

Table 4.7. Mean nutrient concentrations (mg/L) in outflow by quarter for the Parker Tract study site (continued).

Site	Parameter	Statistic	Winter	Spring	Summer	Fall
S4 Outlet	Org-N	Mean	1.95	2.20	2.77	2.04
S4 Outlet	Total N	Mean	5.14	3.69	5.19	3.85
		Std Dev	2.22	1.26	1.79	2.20
		CV	0.43	0.34	0.35	0.57
S4 Outlet	Total P	Mean	0.210	0.047	0.082	0.026
		Std Dev	0.010	0.030	0.143	0.017
		CV	0.05	0.64	1.74	0.65
F4	NO_3-N	Mean	0.78	1.60	0.20	1.05
		Std Dev	1.02	N/A	N/A	1.25
		CV	1.31	N/A	N/A	1.19
F4	NH_4-N	Mean	0.68	0.14	0.70	0.38
		Std Dev	0.70	N/A	N/A	0.19
		CV	1.03	N/A	N/A	0.50
F4	DIN	Mean	1.46	1.74	0.90	1.43
F4	Org-N	Mean	4.14	3.56	2.40	3.53
F4	Total N	Mean	5.60	5.30	3.30	4.96
		Std Dev	2.34	N/A	N/A	0.54
		CV	0.42	N/A	N/A	0.11
F4	Total P	Mean	0.175	0.050	0.100	0.098
		Std Dev	0.249	N/A	N/A	0.053
		CV	1.42	N/A	N/A	0.54
F7	NO_3-N	Mean	0.83	1.73	0.15	0.53
		Std Dev	1.21	0.67	0.07	1.02
		CV	1.45	0.38	0.47	1.91
F7	NH_4-N	Mean	0.16	0.34	0.45	0.37
		Std Dev	0.12	0.30	0.07	0.05
		CV	0.79	0.87	0.16	0.14
F7	DIN	Mean	0.99	2.08	0.60	0.90
F7	Org-N	Mean	2.90	3.22	2.90	3.60
F7	Total N	Mean	3.89	5.30	3.50	4.50
		Std Dev	1.23	0.20	0.42	0.91
		CV	0.32	0.04	0.12	0.20
F7	Total P	Mean	0.031	0.043	0.055	0.052
		Std Dev	0.003	0.021	0.007	0.017
		CV	0.10	0.49	0.13	0.33

concentration increased from 0.14 to 0.28 mg/L for F1 (mostly mineral) to 1.2 to 3.9 mg/L for F3 (mineral with more organic content).

For all monitoring locations in the Parker Tract study site, the majority of the DIN was in the form of NO_3-N (Table 4.7). The seasonal average NO_3-N concentrations were lowest for the mineral soil (0.07 to 0.2 mg/L) and highest for the organic soil with managed pine plantation (F5 and F6), ranging from 0.7 to 8.8 mg/L. The NO_3-N concentration in drainage from the mineral soils at the Parker Tract with high organic content were intermediate at 1.0 to 3.4 mg/L, while average concentrations for organic soil with natural vegetation were somewhat lower at 0.15 to 1.7 mg/L. Similar to Org-N, the NH_4-N concentrations increased with organic content for the mineral soil blocks from 0.03 to 0.08 mg/L for F1 to 0.18 to 0.43 mg/L for F3. They were highest at 0.14 to 0.77 mg/L for organic soils with either pine plantation or natural vegetation.

Mean seasonal TP concentrations at the Parker Tract were also affected by soil type (Table 4.7). The lowest TP concentrations occurred in water draining from the mineral soils at 0.010 to 0.023 mg/L for F1, F3, and F8. TP concentrations in outflow from the organic soils were generally higher, but mean seasonal concentrations were more variable at 0.02 to 0.18 mg/L.

Van Swamp and Pungo Lake

The Van Swamp watershed included a mixture of forested lands with both managed stands and unditched natural stands. Mean nitrogen concentrations in drainage water from Van Swamp among years generally reflected the combination of organic and mineral soils. Mean seasonal TN concentrations ranged from 1.4 to 2.2 mg/L, with the highest concentrations occurring during the summer (Table 4.8). For all seasons, TN was fairly evenly distributed between DIN and Org-N. Ammonium concentrations, with seasonal means from 0.07 to 0.71 mg/L, were also higher than in many other studies, reflecting the organic soils. The NH_4-N fraction comprised the majority (61 to 65%) of the DIN in the spring and summer quarters but only 6% in the winter when the NO_3-N concentration was highest at 1.1 mg/L. For other seasons, the mean NO_3-N concentration was relatively constant at 0.24 to 0.39 mg/L. The mean TP concentration, similar to NH_4-N and Org-N, was highest during the summer quarter (0.074 mg/L) compared with mean concentrations of 0.024 to 0.031 mg/L for the fall through spring quarters.

Mean nutrient concentrations in drainage from the Pungo Lake study site (natural forest on unditched organic soil) among years showed similarities and differences from Van

Table 4.8. Mean nutrient concentrations (mg/L) in outflow by quarter for the Van Swamp study site.

Site	Parameter	Statistic	Winter	Spring	Summer	Fall
VANS	NO_3-N	Mean	1.06	0.24	0.39	0.25
		Std Dev	0.82	0.33	0.92	0.31
		CV	0.77	1.38	2.38	1.27
VANS	NH_4-N	Mean	0.07	0.37	0.71	0.22
		Std Dev	0.02	0.49	0.54	0.24
		CV	0.31	1.32	0.76	1.11
VANS	DIN	Mean	1.14	0.61	1.09	0.46
VANS	Org-N	Mean	0.81	0.94	1.13	0.96
VANS	Total N	Mean	1.94	1.55	2.22	1.43
		Std Dev	1.17	0.70	0.90	0.61
		CV	0.60	0.46	0.41	0.43
VANS	Total P	Mean	0.031	0.029	0.074	0.024
		Std Dev	0.042	0.029	0.050	0.021
		CV	1.36	0.98	0.68	0.89

Swamp. Mean TN concentrations in outflow from the Pungo Lake site ranged from 1.1 to 1.5 mg/L, with the highest seasonal average occurring in the summer quarter (Table 4.9). In contrast to Van Swamp, seasonal mean NO_3-N concentrations were uniformly low at 0.01 to 0.05 mg/L. The NH_4-N concentration in outflow was not determined in the study. Like at Van Swamp, TP concentrations were also highest during the summer quarter at 0.07 mg/L compared with 0.02 to 0.03 mg/L for fall through spring.

Croatan/Craven 40

The two monitoring locations in the Craven 40 Tract drained areas that were either all managed pine forests (HA3) or a combination of managed pine forest and natural forest (HA1), while the monitoring location in the adjacent Croatan National Forest drained areas that were all unditched natural forest (CR43). The mean N concentrations in outflow from all of these areas among years generally reflected the mineral nature of the soils. Mean DIN concentrations were low for all three sites in all seasons, with quarterly average values ranging from 0.02 to 0.15 mg/L (Table 4.10). Seasonal NH_4-N and NO_3-N mean concentrations were less than 0.1 mg/L, with NO_3-N accounting for 60% to 94% of the DIN pool. The exception to the extremely low DIN levels occurred during the winter quarter when mean NO_3-N from HA3 was 0.15 mg/L. The high contribution of NO_3-N to DIN was particularly true for the CR43 and HA1 sites, which had mucky soils along the streams. For all three sites, most of TN in outflow from

Table 4.9. Mean nutrient concentrations (mg/L) in outflow by quarter for the Pungo Lake study site.

Site	Parameter	Statistic	Winter	Spring	Summer	Fall
PL	NO_3-N	Mean	0.017	0.014	0.050	0.010
		Std Dev	0.009	0.014	0.101	0.000
		CV	0.52	1.02	2.03	0.00
PL	NH_4-N	Mean	N/A	N/A	N/A	N/A
PL	TKN	Mean	1.16	1.28	1.47	1.05
		Std Dev	0.15	0.14	0.30	0.40
		CV	0.13	0.11	0.21	0.38
PL	Org-N	Mean	N/A	N/A	N/A	N/A
PL	Total N	Mean	1.16	1.28	1.51	1.06
		Std Dev	0.15	0.14	0.33	0.39
		CV	0.13	0.11	0.22	0.37
PL	Total P	Mean	0.016	0.032	0.074	0.033
		Std Dev	0.007	0.015	0.083	0.015
		CV	0.47	0.46	1.12	0.46

the CR43 (93 to 96%), HA1 (86 to 94%), and HA3 (71 to 94%) subwatersheds occurred as Org-N. Seasonally, the highest Org-N concentrations occurred in the summer quarter at all three locations. Average quarterly concentrations of TP ranged from 0.02 to 0.04 mg/L for HA3 and CR43 and from 0.06 to 0.09 mg/L for HA1. No clear seasonal pattern was observed across the three sites.

Carteret County - Open Grounds Farm

The three monitoring locations surveyed by Kirby-Smith and Barber (1979) represented a natural pocosin on unditched organic soils (OG8), a mixture of managed pine, natural pine, and hardwood forest on both ditched and unditched mineral soils (OG1), and a natural pine forest on a mixture of unditched mineral and organic soils (OG10). Nitrogen concentrations in outflow from the sites were dominated by organic fractions. The particle-bound Org-N (PON) concentration in outflow from OG8 (pocosin) and OG10 (pine) averaged 0.09 to 0.24 mg/L and 0.30 to 0.40 mg/L, respectively. PON concentrations were higher than seasonally averaged DIN concentrations (Table 4.11). Notably, the apparent dominance of the organic N fractions of TN would have been even more pronounced if the dissolved organic component of Org-N (DON) had been determined in the study. It is likely that DON was the dominant TN fraction in outflows from the sites given the organic muck soils present. Seasonally, there was little difference in the PON concentration for drainage from the wetland forest (OG10), but PON in the pocosin outflow (OG8) reached a seasonal minimum in the spring (0.09 mg/L) and maximum in the fall (0.25 mg/L). The DIN concentrations at the sites were generally low, with seasonal means of 0.02 to 0.27 mg/L; DIN was lowest in the pocosin (OG8) outflow. Seasonally, the mean DIN concentration in outflow from OG8 was highest in the summer compared with peak concentrations in the fall from the OG1 and OG10 pine blocks. For DIN, NH_4-N contributed a majority of the total in outflow from OG8 (81 to 88%) compared with 16 to 67% of DIN in outflow from the pine stands. Average PO_4-P concentrations were low at the sites, remaining less than 0.03 mg/L for all quarters except OG10 during spring (0.064 mg/L).

Table 4.10. Mean nutrient concentrations (mg/L) in outflow by quarter at the Croatan/Craven 40 study site. Soil types were: (HA1) mineral + organic; (HA3) mineral; and (CR43) mineral.

Site	Parameter	Statistic	Winter	Spring	Summer	Fall
HA1	NO_3-N	Mean	0.040	0.012	0.021	0.027
		Std Dev	0.046	0.011	0.024	0.036
		CV	1.15	0.92	1.14	1.33
HA1	NH_4-N	Mean	0.059	0.039	0.045	0.079
		Std Dev	0.046	0.046	0.035	0.163
		CV	0.78	1.18	0.78	2.06
HA1	DIN	Mean	0.10	0.05	0.07	0.11
HA1	Org-N	Mean	0.63	0.75	1.05	0.74
HA1	Total N	Mean	0.73	0.80	1.11	0.85
HA1	Total P	Mean	0.086	0.090	0.064	0.084
		Std Dev	0.062	0.086	0.021	0.071
		CV	0.72	0.96	0.33	0.85
HA3	NO_3-N	Mean	0.149	0.044	0.041	0.047
		Std Dev	0.061	0.036	0.002	0.039
		CV	0.41	0.82	0.05	0.83
HA3	NH_4-N	Mean	0.000	0.006	0.001	0.004
		Std Dev	0.000	0.003	0.002	0.002
		CV	0.00	0.50	2.00	0.50
HA3	DIN	Mean	0.15	0.05	0.04	0.05
HA3	Org-N	Mean	0.37	0.40	0.67	0.35
HA3	Total N	Mean	0.52	0.45	0.71	0.40
HA3	Total P	Mean	0.026	0.035	0.030	0.037
		Std Dev	0.010	0.019	0.010	0.019
		CV	0.38	0.54	0.33	0.51
CR43	NO_3-N	Mean	0.015	0.021	0.032	0.015
		Std Dev	0.004	0.012	0.007	0.006
		CV	0.27	0.57	0.22	0.40
CR43	NH_4-N	Mean	0.003	0.012	0.011	0.002
		Std Dev	0.005	0.006	0.013	0.002
		CV	1.67	0.50	1.18	1.00
CR43	DIN	Mean	0.02	0.03	0.04	0.02
CR43	Org-N	Mean	0.36	0.46	0.95	0.46
CR43	Total N	Mean	0.38	0.49	0.99	0.48
CR43	Total P	Mean	0.020	0.031	0.023	0.018
		Std Dev	0.012	0.009	0.006	0.008
		CV	0.60	0.29	0.26	0.44

Weyerhaeuser Multi-Tract Study

Mean nutrient concentration data for the 11 forest subwatersheds in the Weyerhaeuser multi-tract study (Parker Tract omitted) are presented on pages

Table 4.11. Mean nutrient concentrations (mg/L) in outflow by quarter at the Open Grounds Farm site. Vegetation for study blocks were: (OG1) managed pine; (OG8) natural pocosin; and (OG10) natural forest. Total concentrations of N and P were not determined in the study.

Site	*Parameter*	*Statistic*	*Winter*	*Spring*	*Summer*	*Fall*
OG1	NO_3-N	Mean	0.012	0.019	0.093	0.180
		Std Dev	0.012	0.018	0.086	0.290
		CV	1.00	0.95	0.92	1.61
OG1	NH_4-N	Mean	0.004	0.022	0.017	0.089
		Std Dev	0.003	0.022	0.018	0.108
		CV	0.75	1.00	1.06	1.21
OG1	DIN	Mean	0.02	0.04	0.11	0.27
OG1	PON	Mean	0.061	N/A	N/A	N/A
		Std Dev	N/A	N/A	N/A	N/A
		CV	N/A	N/A	N/A	N/A
OG1	Total N	Mean	N/A	N/A	N/A	N/A
OG1	PO_4-P	Mean	0.008	0.006	0.015	0.017
		Std Dev	0.002	0.003	0.017	0.015
		CV	0.25	0.50	1.13	0.88
OG1	Total P	Mean	N/A	N/A	N/A	N/A
OG8	NO_3-N	Mean	0.003	0.005	0.005	0.005
		Std Dev	0.002	0.004	0.003	0.006
		CV	0.67	0.80	0.60	1.20
OG8	NH_4-N	Mean	0.015	0.029	0.038	0.021
		Std Dev	0.074	0.033	0.042	0.015
		CV	4.93	1.14	1.11	0.71
OG8	DIN	Mean	0.02	0.03	0.04	0.03
OG8	PON	Mean	0.102	0.085	0.165	0.245
		Std Dev	0.071	N/A	0.163	N/A
		CV	0.70	N/A	0.99	N/A
OG8	Total N	Mean	N/A	N/A	N/A	N/A
OG8	PO_4-P	Mean	0.011	0.010	0.010	0.012
		Std Dev	0.007	0.006	0.003	0.007
		CV	0.64	0.60	0.30	0.58
OG8	Total P	Mean	N/A	N/A	N/A	N/A
OG10	NO_3-N	Mean	0.045	0.024	0.049	0.132
		Std Dev	0.068	0.033	0.044	N/A
		CV	1.51	1.38	0.90	N/A
OG10	NH_4-N	Mean	0.055	0.013	0.101	0.133
		Std Dev	0.074	0.014	0.055	0.113
		CV	1.35	1.08	0.54	0.85
OG10	DIN	Mean	0.10	0.04	0.15	0.27
OG10	PON	Mean	0.322	0.396	0.303	0.351
		Std Dev	0.239	0.089	0.196	0.220
		CV	0.74	0.22	0.65	0.63
OG10	Total N	Mean	N/A	N/A	N/A	N/A
OG10	PO_4-P	Mean	0.009	0.064	0.013	0.024
		Std Dev	0.009	0.008	0.014	N/A
		CV	1.00	0.13	1.08	N/A
OG10	Total P	Mean	N/A	N/A	N/A	N/A

48 and 49 by predominant soil type (mineral vs. organic) since soil characteristics appeared to affect N and P concentrations in outflows. For example, TN in outflow from organic soils occurred mainly as Org-N, and DIN occurred mainly as NH_4-N. In contrast, TN in outflow from mineral soils was generally evenly proportioned between DIN and Org-N, with the majority of DIN as NO_3-N. Other factors potentially influencing N and P concentrations and dominant fractions were elevation and slope across the subwatershed, ditch spacing and soil hydraulic conductivity, specific soil type (e.g., order and series), age and species composition of the forest canopy, and landscape position relative to the Suffolk Scarp. All of the study sites were managed forest on ditched soil. Data presented for the 11 forest subwatersheds are limited to the winter and spring quarters, which was the focus of the study; limited data from the fall period are omitted. The S4 outlet from the Parker Tract was included in the study, but results are summarized separately (see Table 4.7).

Mineral Soil Sites

Seven of the eleven subwatersheds had large areas with mineral soils. Seasonal nutrient data for those seven soil sites are presented in Table 4.12. Mean nutrient concentrations are described below by site beginning with those west of the Suffolk Scarp. Five sites were west of the scarp at an elevation of more than 12 m; the Kramer Tract (el. 6 m) and the Hyde 15 Tract (el. 1.5 m) were east of the scarp.

J&W-1. The mean TN concentration in outflow was 1.53 mg/L during the winter quarter and somewhat lower at 1.26 mg/L in the spring. For the winter quarter, a majority of TN was contributed by DIN (0.94 mg/L), primarily (97%) in the form of NO_3-N. Nitrate was also the dominant form of DIN in the spring quarter (93%), but DIN (0.60 mg/L) and Org-N (0.67 mg/L) contributed

Table 4.12. Mean N and P concentrations (mg/L) in outflow for the Weyerhaeuser multi-tract study by subwatershed and quarter.

Para-		Abbott Tract		Bates Bay		Big Pocosin		Hyde 15		J&W-1		J&W-2	
meter	Statistic	Winter	Spring	Winter	Spring	Winter	Spring	Winter	Spring	Winter	Spring	Winter	Spring
NO_3-N	Count	18	11	18	12	18	12	9	5	17	10	14	9
	Mean	0.89	0.33	0.85	0.20	0.90	0.29	1.87	0.66	0.91	0.56	0.64	0.28
	Std Dev	0.81	0.51	0.62	0.16	0.87	0.18	1.38	0.83	0.65	0.55	0.44	0.21
	CV	0.91	1.57	0.73	0.82	0.96	0.62	0.74	1.27	0.72	0.98	0.70	0.75
NH_4-N	Count	18	11	18	12	18	12	9	5	17	10	14	9
	Mean	0.109	0.031	0.054	0.126	0.030	0.082	0.063	0.316	0.028	0.040	0.009	0.035
	Std Dev	0.127	0.022	0.030	0.083	0.021	0.070	0.048	0.352	0.038	0.030	0.010	0.029
	CV	1.16	0.71	0.55	0.66	0.73	0.86	0.75	1.11	1.34	0.76	1.08	0.82
DIN	Count	18	11	18	12	18	12	9	5	17	10	14	9
	Mean	1.00	0.36	0.90	0.32	0.93	0.37	1.93	0.97	0.94	0.60	0.64	0.32
	Std Dev	0.84	0.52	0.63	0.12	0.87	0.17	1.36	0.90	0.65	0.55	0.44	0.20
	CV	0.85	1.46	0.69	0.39	0.94	0.44	0.71	0.92	0.69	0.92	0.68	0.64
Org-N	Count	18	11	18	12	18	12	9	5	17	10	14	9
	Mean	1.46	1.40	1.31	1.39	0.72	0.96	0.59	0.66	0.59	0.67	0.35	0.37
	Std Dev	0.26	0.15	0.17	0.22	0.22	0.36	0.17	0.16	0.22	0.15	0.11	0.19
	CV	0.18	0.11	0.13	0.16	0.30	0.37	0.28	0.25	0.37	0.22	0.31	0.51
Total N	Count	18	11	18	12	18	12	9	5	17	10	14	9
	Mean	2.46	1.76	2.21	1.71	1.65	1.33	2.52	1.63	1.53	1.26	1.00	0.68
	Std Dev	1.02	0.55	0.76	0.21	0.87	0.37	1.37	1.03	0.65	0.53	0.49	0.17
	CV	0.41	0.32	0.35	0.12	0.53	0.28	0.54	0.63	0.42	0.42	0.49	0.25
Total P	Count	18	11	18	12	18	12	9	5	17	10	14	9
	Mean	0.047	0.027	0.125	0.118	0.070	0.049	0.141	0.049	0.050	0.026	0.041	0.034
	Std Dev	0.024	0.013	0.043	0.054	0.040	0.035	0.108	0.019	0.029	0.018	0.028	0.032
	CV	0.50	0.49	0.35	0.46	0.57	0.71	0.76	0.40	0.57	0.67	0.69	0.92

(Table continued on next page)

equally to TN. The change in relative proportions of organic vs. inorganic fractions between the winter and spring periods was largely due to the variation in NO_3-N concentration (0.91 vs. 0.56 mg/L); mean NH_4-N and Org-N concentrations were similar for winter and spring quarters. Mean total P concentration was low during both quarters at 0.026 to 0.050 mg/L.

J&W-2. Mean TN concentrations in outflow from JW2 ranged from 0.68 to 1.0 mg/L for the spring and winter quarters, with the lower spring mean value due to a corresponding decrease in NO_3-N. For the winter quarter, NO_3-N was the dominant TN fraction at 0.64 mg/L (64% of TN) compared with 42% of TN in the spring quarter (0.28 of 0.68 mg/L). As with JW1, the seasonal variation in Org-N concentration was small at 0.35 to 0.37 mg/L. Mean TP concentrations were also similar to those from JW1 at 0.034 and 0.041 mg/L.

J&W-3. In contrast to other subwatersheds in the J&W Tract, the mean TN concentration in outflow from JW3 showed only a small variation with season (1.16 to 1.31 mg/L), with a higher mean value for the spring quarter. For JW3, the mean DIN concentration, and NO_3-N in particular, were similar for both seasons at 0.60 and 0.62 mg/L. The small seasonal variation in TN concentrations between mean values for winter and spring months was due to a higher Org-N concentration in the spring (0.71 mg/L) than in the winter (0.55 mg/L). Overall, DIN contributed 53% of TN in the winter but only 46% in the spring, with NO_3-N as the dominant (95 to 97 %) DIN fraction. The greater Org-N contribution to TN in outflow from the JW3 subwatershed may reflect organic muck soils near the drainage system outlet. Mean TP concentration in outflow was low at 0.043 to 0.047 mg/L.

J&W-4. The mean TN concentration in outflow from this subwatershed just upslope from the Suffolk Scarp averaged 0.71 and 1.02 mg/L, with higher concentrations during the winter. This seasonal difference, as with JW1 and JW2, was largely due to much higher mean DIN in the winter quarter than during the spring (0.62 vs. 0.39 mg/L), mainly as NO_3-N. Mean Org-N was similar for both seasons at 0.33 and 0.41 mg/L, as was mean TP concentration at 0.026 and 0.034 mg/L.

Big Pocosin. Seasonal variations in mean Org-N, NH_4-N, and NO_3-N concentrations in outflow were ob-

Table 4.12. Mean N and P (mg/L) concentrations in ouflow for the Weyerhaeuser multi-tract study by subwatershed and quarter *(continued)*.

Parameter	Statistic	J&W-3		J&W-4		Kramer Tract		Morrison Tract		Rodman-Meyer		Parker Tract	
		Winter	Spring	Winter	Spring	Winter	Spring	Winter	Spring	Winter	Spring	Winter	Spring
NO_3-N	Count	20	12	15	7	16	10	16	10	18	11	17	10
	Mean	0.60	0.57	0.60	0.34	0.74	0.47	0.88	0.54	0.69	0.22	2.72	1.07
	Std Dev	0.45	0.80	0.43	0.28	0.56	0.40	0.91	0.68	0.57	0.24	1.66	1.09
	CV	0.75	1.41	0.72	0.82	0.76	0.86	1.04	1.26	0.83	1.09	0.61	1.02
NH_4-N	Count	20	12	15	7	16	10	16	10	18	11	17	10
	Mean	0.015	0.030	0.015	0.043	0.083	0.184	0.418	0.567	0.035	0.104	0.090	0.225
	Std Dev	0.010	0.026	0.012	0.070	0.133	0.201	0.131	0.283	0.022	0.113	0.063	0.232
	CV	0.67	0.84	0.85	1.62	1.61	1.09	0.31	0.50	0.63	1.09	0.70	1.03
DIN	Count	20	12	15	7	16	10	16	10	18	11	17	10
	Mean	0.62	0.60	0.62	0.39	0.82	0.65	1.30	1.10	0.72	0.33	2.81	1.29
	Std Dev	0.45	0.81	0.43	0.26	0.57	0.31	0.88	0.69	0.56	0.26	1.62	0.99
	CV	0.74	1.36	0.69	0.66	0.69	0.48	0.68	0.62	0.78	0.80	0.58	0.76
Org-N	Count	20	12	15	7	16	10	16	10	18	11	17	10
	Mean	0.55	0.71	0.41	0.33	0.45	0.70	2.95	3.22	0.76	0.83	1.64	1.72
	Std Dev	0.11	0.30	0.23	0.06	0.20	0.53	0.30	0.39	0.16	0.18	0.29	0.60
	CV	0.21	0.42	0.58	0.20	0.45	0.75	0.10	0.12	0.22	0.22	0.18	0.35
Total N	Count	20	12	15	7	16	10	16	10	18	11	17	10
	Mean	1.16	1.31	1.02	0.71	1.27	1.35	4.25	4.33	1.48	1.16	4.45	3.01
	Std Dev	0.50	0.89	0.47	0.26	0.67	0.56	0.98	0.95	0.65	0.30	1.82	1.21
	CV	0.43	0.68	0.46	0.36	0.52	0.41	0.23	0.22	0.44	0.26	0.41	0.40
Total P	Count	20	12	15	7	16	10	16	10	18	11	17	10
	Mean	0.043	0.047	0.034	0.026	0.072	0.053	0.169	0.196	0.060	0.044	0.098	0.071
	Std Dev	0.024	0.032	0.021	0.017	0.045	0.042	0.062	0.085	0.033	0.035	0.056	0.051
	CV	0.56	0.67	0.62	0.66	0.63	0.80	0.37	0.43	0.55	0.78	0.57	0.72

served during the study period. The TN concentration in outflow was higher during the winter quarter with a mean value of 1.65 mg/L compared with a mean value of 1.33 mg/L in the spring. During the winter quarter, DIN accounted for 56% of TN, primarily as NO_3-N (97%). In contrast, Org-N contributed 72% of TN in the spring quarter due to an increase in Org-N concentration (0.96 vs. 0.72 mg/L) and a decrease in DIN (0.37 vs. 0.93 mg/L) compared with mean values for the winter quarter. The mean TP concentration was higher than at the J&W sites at 0.049 and 0.070 mg/L for quarterly mean values.

Kramer Tract. Mean TN concentration in outflow from the Kramer Tract averaged 1.27 to 1.35 mg/L by quarter. However, there was a shift in the dominant forms of N between the winter and spring quarters. Nitrate (0.74 mg/L) contributed 58% of TN during the winter quarter, while Org-N (0.70 mg/L) and NH_4-N (0.18 mg/L) contributed 52% and 13% of TN for the spring quarter mean, respectively. The mean TP concentrations at this site were 0.053 and 0.072 mg/L, respectively, for the spring and winter quarters.

Hyde 15. There were fewer water samples from this subwatershed than from the others due to minimal outflow during winter/spring 1999 associated with leakage around the weir structure. The mean TN concentration for the nine winter samples collected was 2.52 mg/L compared with a springtime mean concentration of 1.63 mg/L (n=5). During the winter quarter, TN was composed mostly of DIN (avg. 1.93 mg/L, 77%), predominantly as NO_3-N, while the much lower mean TN concentration in the spring quarter was due to a large decrease in mean NO_3-N concentration (0.66 vs. 1.87 mg/L) compared with the winter quarter. In the spring quarter, DIN concentration (0.97 mg/L) was also higher than Org-N (0.66 mg/L), with NH_4-N contributing 33% of DIN. Mean TP concentration varied by season from 0.049 mg/L during the spring to 0.14 mg/L during the winter.

Organic Soil Sites

Four sites were sampled that have predominantly organic soils, in addition to the S4 outlet from the Parker Tract. They ranged in elevation from 18 m west of the Suffolk Scarp to 1.5 m in the outer coastal plain. Two of the sites at

Table 4.13. Mean quarterly concentrations of Org-N, DIN, Total N, and Total P observed in outflow from all of the full-year study sites.

	Winter mg/L	Spring mg/L	Summer mg/L	Fall mg/L	Winter mg/L	Spring mg/L	Summer mg/L	Fall mg/L
	Org-N				**DIN**			
D1	0.35	0.37	0.56	0.57	0.61	0.61	0.50	0.46
B	0.81	0.66	0.75	0.58	0.12	0.08	0.09	0.04
D	0.42	0.59	0.64	0.47	0.07	0.09	0.06	0.05
UD1	1.11	1.05	1.19	0.87	0.13	0.20	0.09	0.03
J5	0.36	0.51	0.62	0.57	0.27	0.05	0.10	0.22
T102	0.59	0.85	1.61	0.91	0.14	0.12	0.29	0.36
T104	0.98	0.96	1.50	1.27	0.12	0.13	0.10	0.09
T107	0.91	0.98	1.40	1.23	0.04	0.04	0.03	0.05
W1	0.59	1.06	1.09	0.64	0.23	0.20	0.43	0.15
F1-F3-F8	0.39	0.54	0.94	0.47	0.74	0.80	1.85	0.88
F4-F7	3.52	3.39	2.65	3.57	1.22	1.91	0.75	1.17
F5-F6	2.70	2.77	3.60	3.06	2.92	2.53	5.98	2.80
VANS	0.81	0.94	1.13	0.96	1.14	0.61	1.09	0.46
PL								
CR43	0.36	0.46	0.95	0.46	0.02	0.03	0.04	0.02
HA1	0.63	0.75	1.05	0.74	0.10	0.05	0.07	0.11
HA3	0.37	0.40	0.67	0.35	0.15	0.05	0.04	0.05
	Total-N				**Total-P**			
D1	0.96	0.98	1.06	1.03	0.048	0.064	0.013	0.032
B	0.93	0.74	0.84	0.62	0.063	0.095	0.071	0.096
D	0.49	0.68	0.70	0.52	0.023	0.079	0.063	0.060
UD1	1.24	1.25	1.28	0.90	0.043	0.066	0.051	0.028
J5	0.63	0.56	0.72	0.78	0.024	0.023	0.043	0.028
T102	0.69	1.17	1.77	1.19	0.025	0.043	0.066	0.100
T104	1.10	1.09	1.60	1.36	0.044	0.051	0.120	0.044
T107	0.94	1.02	1.43	1.28	0.050	0.021	0.079	0.021
W1	0.82	1.26	1.52	0.79	0.046	0.063	0.045	0.018
F1-F3-F8	1.13	1.34	2.79	1.36	0.016	0.016	0.020	0.016
F4-F7	4.74	5.30	3.40	4.73	0.103	0.047	0.078	0.075
F5-F6	5.62	5.30	9.58	5.86	0.041	0.060	0.065	0.074
VANS	1.94	1.55	2.22	1.43	0.031	0.029	0.074	0.024
PL	1.16	1.28	1.51	1.06	0.016	0.032	0.074	0.033
CR43	0.38	0.49	0.99	0.48	0.020	0.031	0.023	0.018
HA1	0.73	0.80	1.11	0.85	0.086	0.090	0.064	0.084
HA3	0.52	0.45	0.71	0.40	0.026	0.035	0.030	0.037

an elevation of approximately 6 m are immediately east of the Suffolk Scarp. Table 4.12 summarizes average N and P concentrations for the winter and spring quarters.

Bates Bay. This subwatershed contains large components of both mineral and organic soils but was grouped with the organic soils based on N and P concentrations in outflow. The mean TN concentration in outflow was higher in the winter quarter (2.21 mg/L) compared with the spring quarter (1.71 mg/L). This seasonal difference was due to the higher mean DIN concentration in the winter quarter (0.90 vs. 0.32 mg/L), with 94% of winter DIN as NO_3-N. Mean Org-N concentrations were similar for both quarters (1.31 and 1.39 mg/L) and were higher than typical values for the mineral soil sites. Mean TP concentrations were also higher in outflow from Bates Bay than in outflow from the mineral sites presented above, with a quarterly average value of 0.12 mg/L.

Rodman-Meyer. The mean TN concentration in outflow from this site was relatively low compared with those of other subwatersheds with organic soils. The average was higher in the winter quarter (1.48 mg/L vs. 1.16 mg/L). For the winter quarter, DIN and Org-N fractions were nearly the same (avg. 0.72 and 0.76 mg/L, respectively). Nitrate (avg. 0.69 mg/L) accounted for 96% of the winter DIN but only two-thirds in the spring (avg. 0.22 of 0.33 mg/L). In the spring quarter, Org-N (avg. 0.83 mg/L) was the dominant (72%) fraction of TN. Mean TP concentrations for the winter and spring quarters were 0.044 to 0.060 mg/L.

Morrison Tract. The mean TN concentration in outflow from the subwatershed sampled at the Morrison Tract was the highest for the multi-tract subwatersheds sampled at 4.25 (winter) to 4.33 (spring) mg/L. In both quarters, Org-N was the dominant fraction of TN (69 to 74%) at 2.95 and 3.22 mg/L, respectively, for the winter and spring quarters. The mean DIN concentration was higher in the winter (avg. 1.30 mg/L), when 68% of DIN was as NO_3-N, than in the spring (1.10 mg/L). For the spring quarter, average NO_3-N and NH_4-N concentrations were approximately equal. The average TP concentration at the site was relatively high at 0.17 and 0.20 mg/L for the winter and spring quarters, respectively, which were the highest values for the 12 sites sampled (including Parker Tract S4).

Abbott Tract. The average TN concentration in outflow was 40% higher in winter (avg. 2.46 mg/L) than in the spring quarter (avg. 1.76 mg/L). For both quarters, average Org-N concentration was similar (winter = 1.46 mg/L; spring = 1.40 mg/L) and contributed the greater part of TN (59 to 79%); Org-N was the dominant fraction during the spring quarter. In terms of DIN, NO_3-N contributed a majority of the total in both seasons. Mean TP concentrations were 0.047 and 0.027 mg/L, respectively, for the winter and spring quarters.

Summary of Nutrient Concentrations

Mean nutrient concentrations in outflow waters from forested lands are usually low compared to those from other land uses. This held true for most of the study sites presented in this report. Drainage water from 50% of the study sites had mean seasonal concentrations of less than 1.5 mg/L for TN, less than 1.1 mg/L for Org-N, less than 0.2 mg/L for DIN, less than 0.1 mg/L for NO_3-N, less than 0.1 mg/L for NH_4-N, and less than 0.07 mg/L for TP (Figs. 4.1 and 4.2). At the 75th percentile level, mean seasonal concentrations in drainage water from the study sites were less than 1.8 mg/L for TN, less than 1.5 mg/L for Org-N, less than 0.65 mg/L for DIN, less than 0.6 mg/L for NO_3-N, less than 0.22 mg/L for NH_4-N, and less than 0.08 mg/L for TP. Notable exceptions to the generally low nutrient concentrations were the much higher nitrogen concentrations observed in the Parker Tract study. Mean seasonal concentrations for drainage water from the Parker Tract sites located on organic soils were as high as 3.6 mg/L for Org-N, 5.9 mg/L for DIN, and 9.6 mg/L for TN (Table 4.13). Of the sites not located at the Parker Tract and sampled throughout the year, Van Swamp had the highest seasonal concentrations for DIN (1.1 mg/L) and TN (2.2 mg/L), and the Tyrrell County mineral soil site (T102) had the highest concentration for Org-N (1.6 mg/L).

Consistent seasonal changes in nutrient concentrations were not evident for most of the observed constituents (Figs. 4.1 and 4.2). The only notable seasonal difference was that Org-N concentration was highest during the summer. Mean Org-N concentrations were the highest in

Table 4.14. Distribution of mean quarterly nutrient concentrations in outflow during winter and spring (see Figures. 4.3 to 4.6). Values are based on all all study sites including the multi-tract study.

Percent of sites	Total-N mg/L	DIN mg/L	ORG-N mg/L	NO_3-N mg/L	NH_4-N mg/L	Total-P mg/L
Winter						
10th Percentile	0.60	0.06	0.36	0.02	0.01	0.022
25th Percentile	0.90	0.14	0.41	0.04	0.02	0.030
Median	1.15	0.62	0.59	0.60	0.06	0.044
75th Percentile	1.73	0.94	0.94	0.86	0.10	0.061
90th Percentile	3.04	1.25	1.96	0.96	0.23	0.110
Spring						
10th Percentile	0.64	0.05	0.39	0.01	0.02	0.025
25th Percentile	0.79	0.11	0.57	0.02	0.04	0.031
Median	1.26	0.33	0.75	0.23	0.06	0.048
75th Percentile	1.40	0.61	1.01	0.55	0.19	0.063
90th Percentile	2.53	1.02	1.95	0.67	0.29	0.092

the summer for 13 out of 16 sites (Table 4.13), with the median value for the summer concentration at 1.02 mg/L compared with 0.60 to 0.76 mg/L for other seasons. This seasonal pattern in Org-N concentrations was reflected in the TN concentrations, with 14 out of 17 sites having the highest TN concentrations in the summer. Median TN concentrations for summer were 1.43 mg/L compared with 0.94 to 1.09 mg/L for the fall through spring quarters. While the median concentration for TP was also highest in the summer (0.064 mg/L) compared with other seasons (0.033 to 0.047 mg/L), TP concentration was highest in the summer for only 6 out of 17 sites.

The mean N concentrations in the water draining the organic soils at the Parker Tract were usually two to four times higher than the highest mean N concentrations observed in all of the other study sites. These observations raised the important question as to whether the Parker Tract site is an anomaly for eastern North Carolina. The multi-tract study was conducted over a range of forested sites to determine whether high N concentrations occur at other forested sites. The N concentrations observed during the winter and spring quarters at the 11 multi-tract sites were combined with those reported in the full-year studies to give a distribution of concentrations for all 28 sites (Table 4.14). For TN, Org-N, DIN, and NO_3-N, an abrupt increase in concentration occurred just above the 90th percentile (Figs. 4.3 to 4.6). Concentrations nearly doubled in this abrupt increase. The two or three sites that had the high values were the Parker Tract sites and the Morrison Tract site from the multi-tract study. These distributions indicate that N concentrations in forest drainage, as seasonal averages, are usually low (less than 2 mg/L for TN, less than 1 mg/L for DIN, and less than 1.5 mg/L for Org-N); however, some site conditions exist that can result in seasonally high N concentrations in forest drainage water exceeding 4 mg/L for TN, exceeding 2 mg/L for DIN, and exceeding 2.5 mg/L for Org-N. The higher N concentrations occurred in less than 10% of the sites. Notably, the Parker Tract sites and the Morrison Tract site were located on organic soils; however, several other sites were also located on organic soils, but did not have high N concentrations in their drainage water. Both the Parker and Morrison tracts are just east of the Suffolk Scarp, thus, physiographic setting may be an important aspect of the site condition.

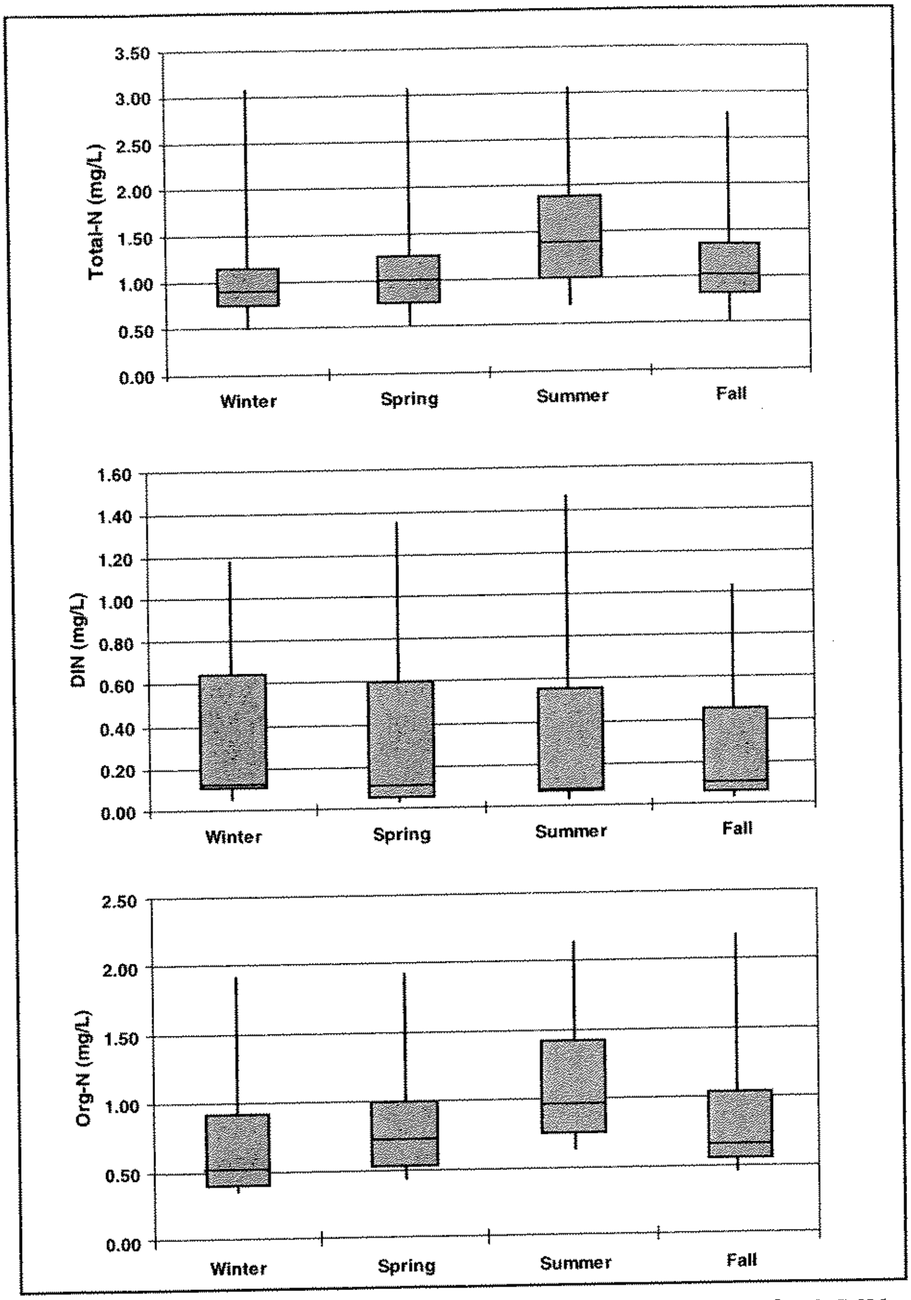


Figure 4.1. Distribution of mean seasonal concentrations of TN, DIN, and Org-N in outflow from full-year study sites. The box and wisker plots show values for 10th, 25th, 50th, 75th, and 90th percentile rankings.

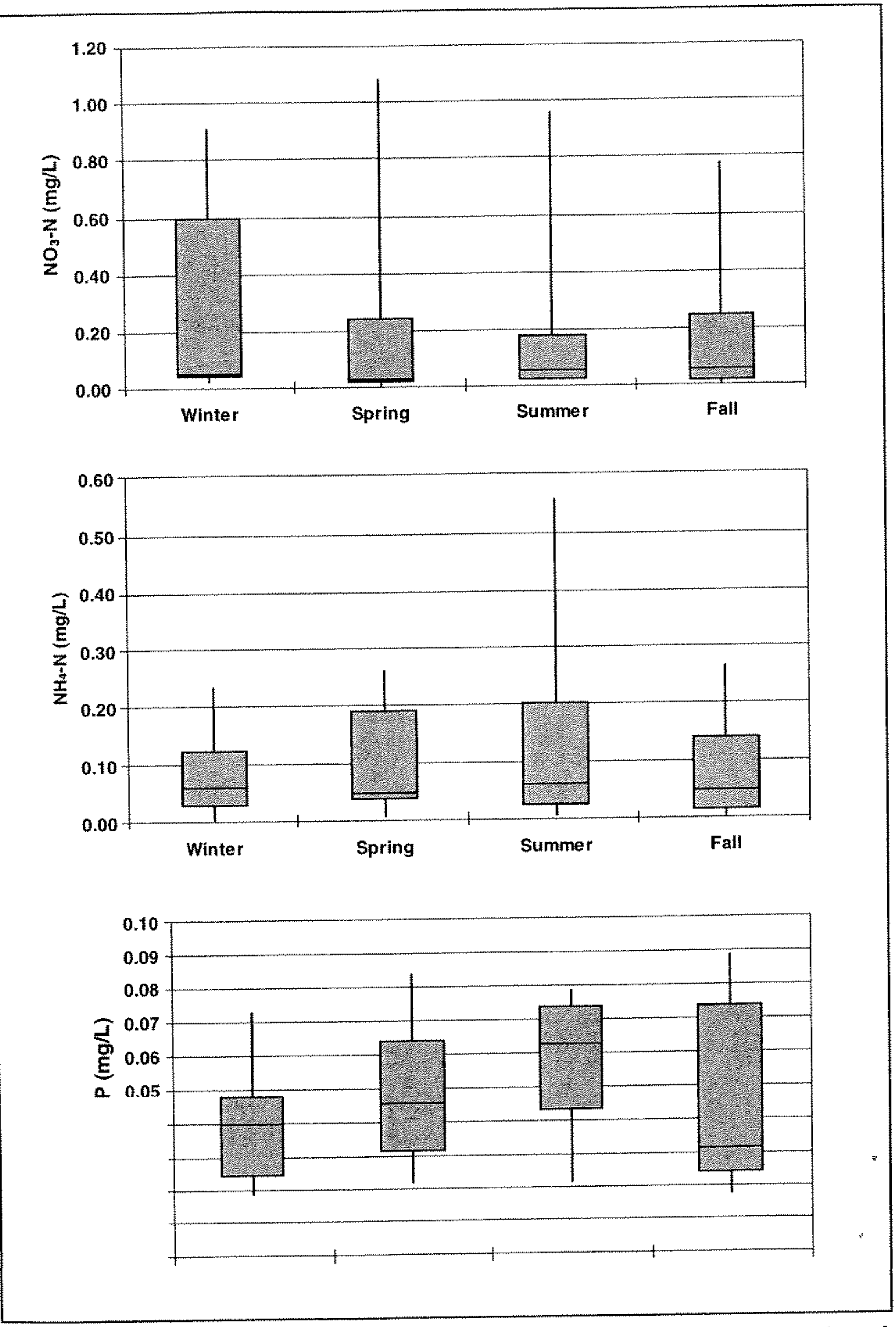


Figure 4.2. Distribution of mean seasonal concentrations of NO_3-N, NH_4-N, and Total P in outflow from full-year study sites. The box and wisker plots show values for 10th, 25th, 75th, and 90th percentile rankings.

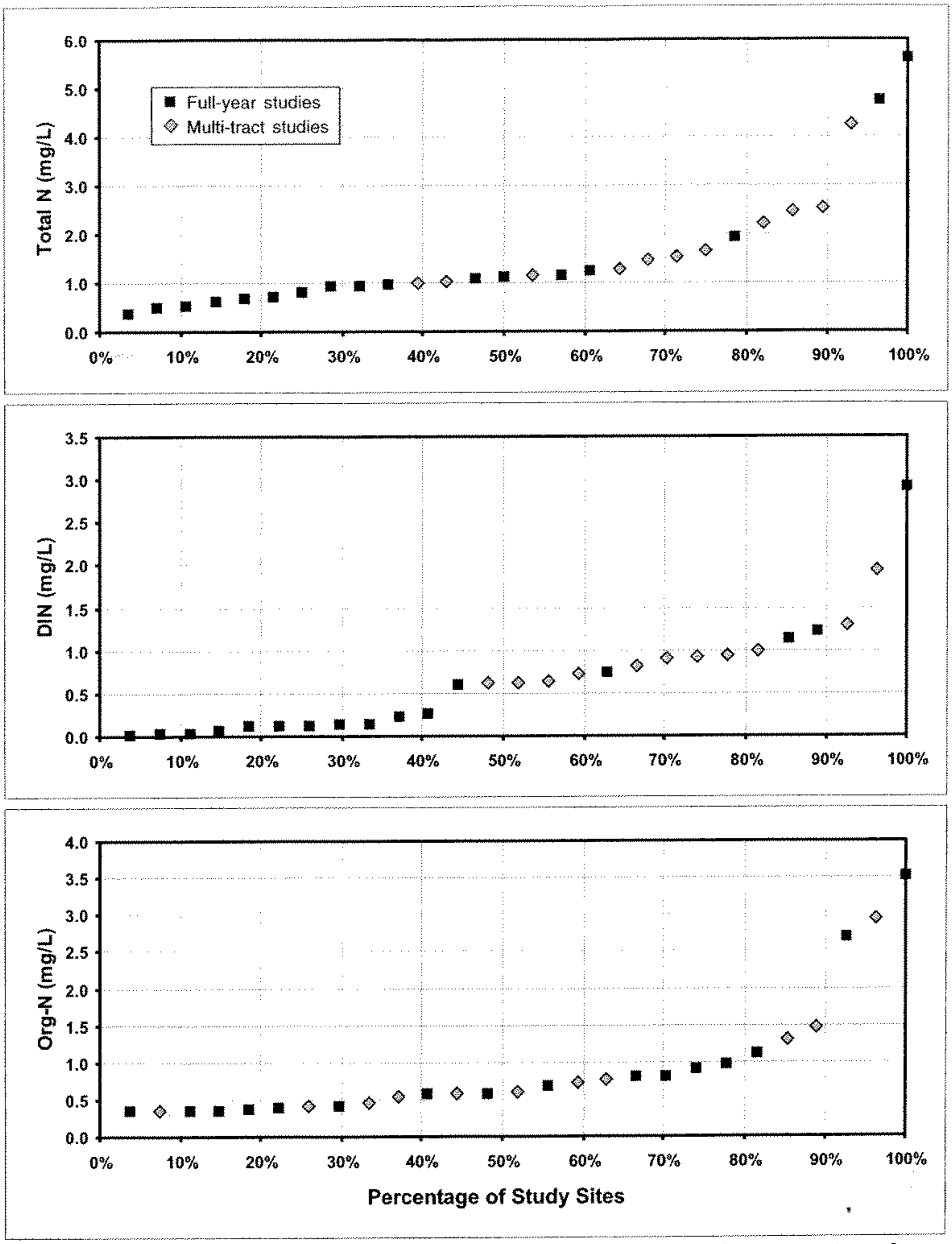


Figure 4.3. Distribution of mean quarterly nutrient concentrations for TN, DIN, and Org-N during winter quarters ranked in ascending order. Plots include data for the multi-tract study sites and the full-year study sites. Replicate sites within studies were averaged and watershed sites that included other study sites were omitted to avoid over-weighting specific locations or conditions.

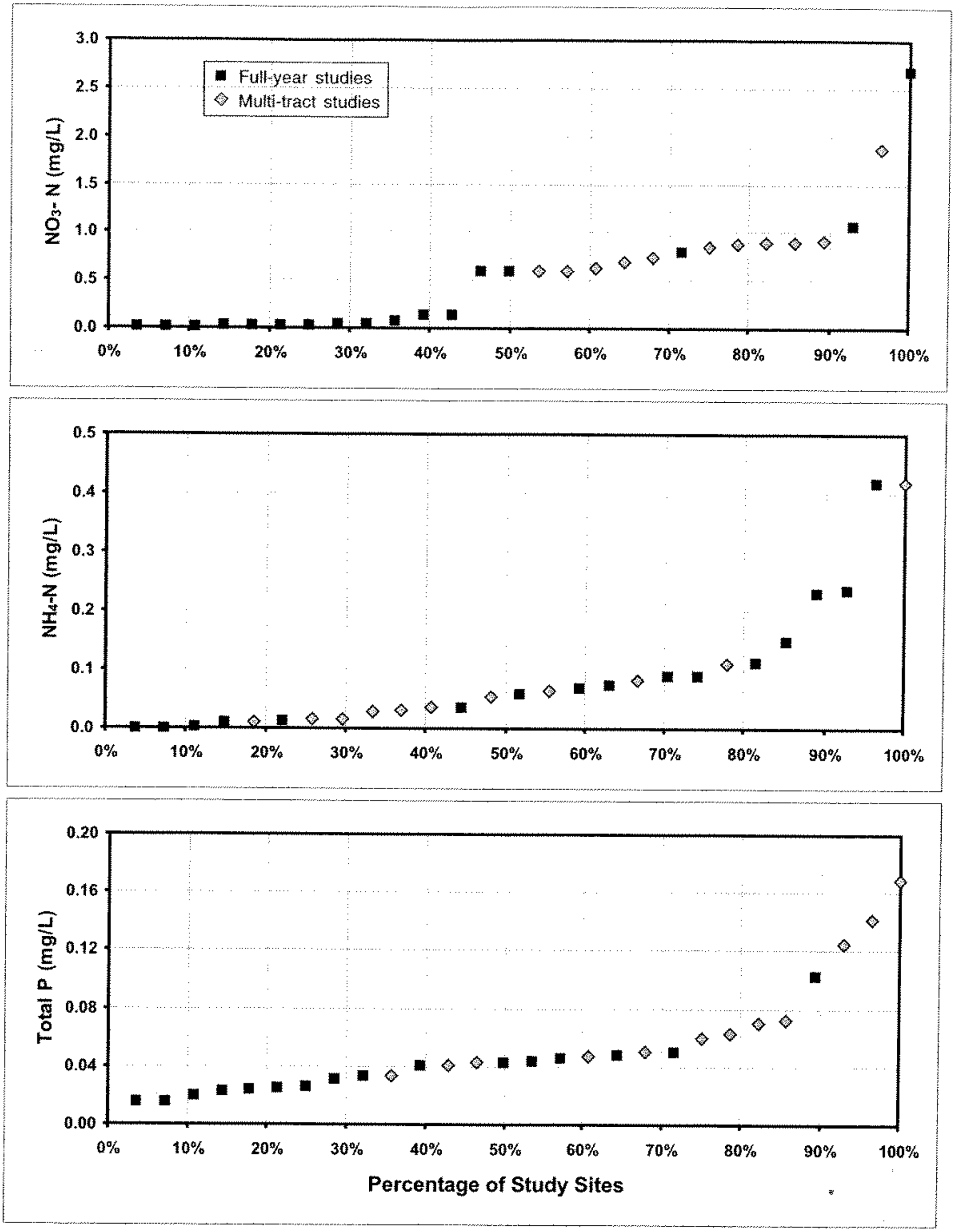


Figure 4.4. Distribution of mean quarterly nutrient concentrations for NO_3-N, NH_4-N, and Total P during winter quarters ranked in ascending order. Plots include data for the multi-tract study sites and the full-year study sites. Replicate sites within studies were averaged and watershed sites that included other study sites were omitted to avoid over-weighting specific locations or conditions.

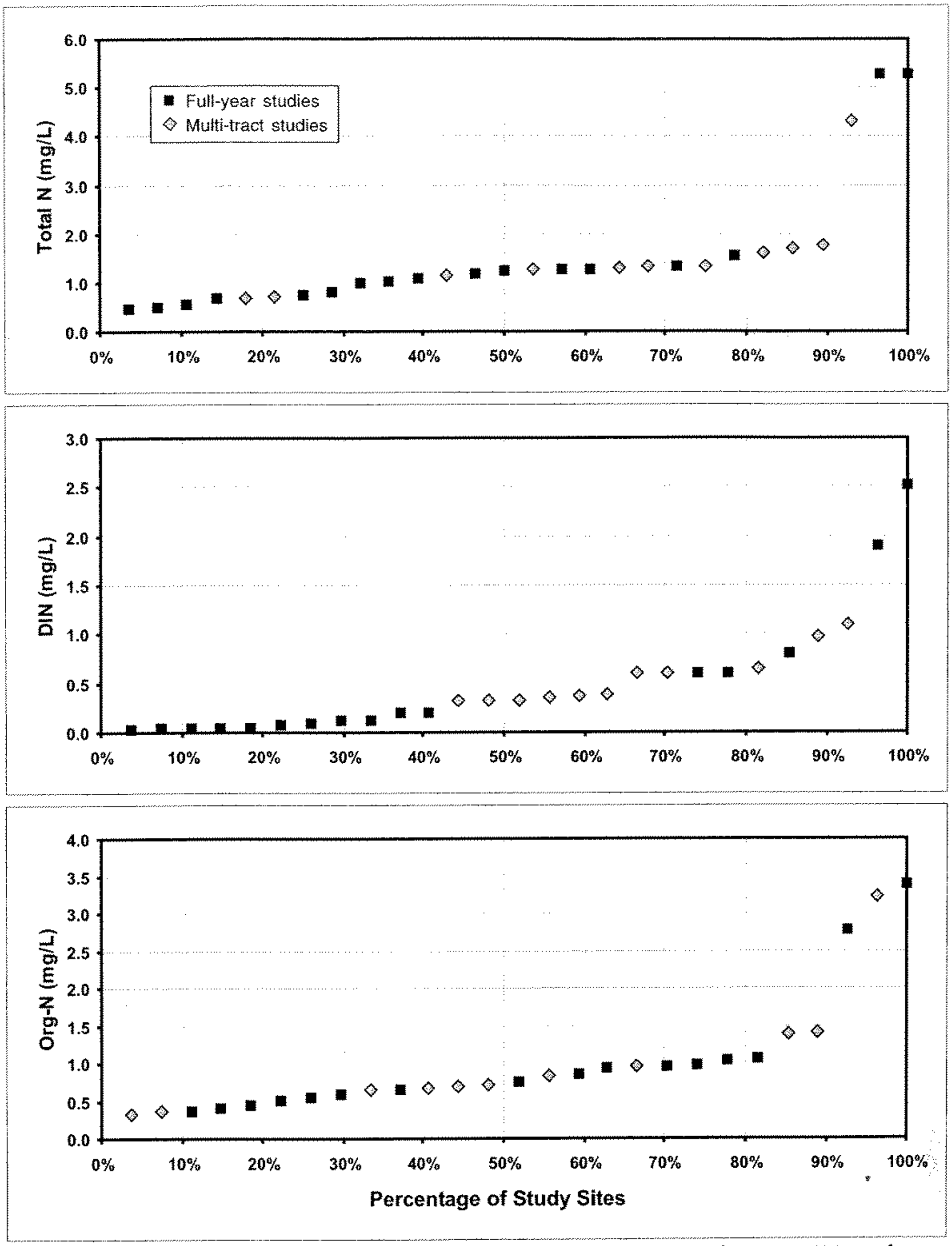


Figure 4.5. Distribution of mean quarterly nutrient concentrations for TN, DIN, and Org-N during spring quarters ranked in ascending order. Plots include data for the multi-tract study sites and the full-year study sites. Replicate sites within studies were averaged and watershed sites that included other study sites were omitted to avoid over-weighting specific locations or conditions.

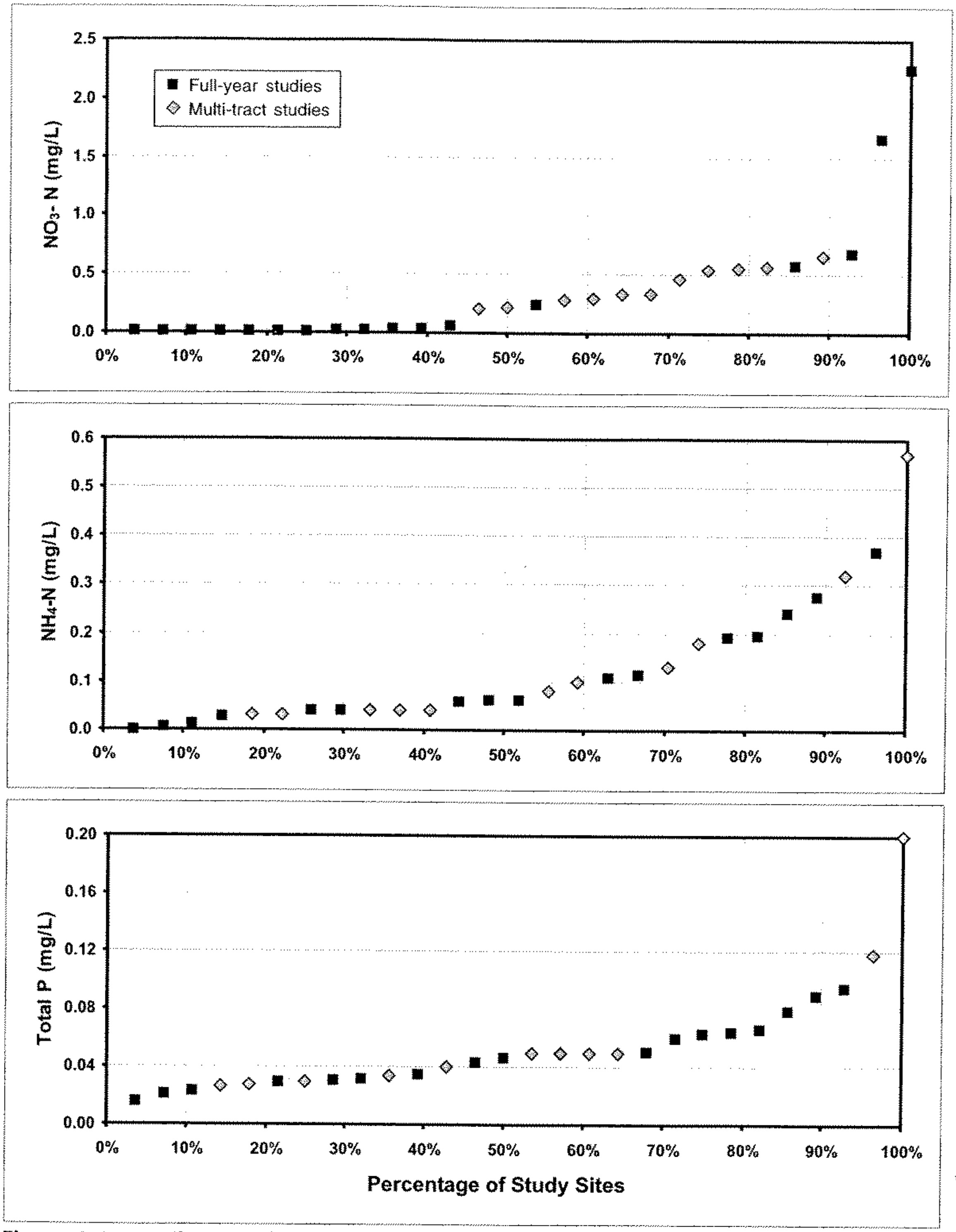


Figure 4.6. Distribution of mean quarterly nutrient concentrations for NO_3-N, NH_4-N, and Total P during spring quarters ranked in ascending order. Plots include data for the multi-tract study sites and the full-year study sites. Replicate sites within studies were averaged and watershed sites that included other study sites were omitted to avoid over-weighting specific locations or conditions.

SECTION 5 - NUTRIENT EXPORTS

The export of nutrients in forest drainage results from the combined effects of outflow volume and nutrient concentrations in the drainage water. Consequently, values for nutrient export can be quantified only from studies that measured both outflow volume and nutrient concentrations (Carteret 7, Isaac Creek, Jones County, Tyrrell County, Washington County, Parker Tract, Van Swamp, and Pungo Lake). Since export depends on outflow volume and outflow volume varies greatly in response to year-to-year and seasonal weather patterns, nutrient exports reported for short-term studies (less than 10 years) must be interpreted in the context of the weather patterns observed during the study.

As discussed earlier, nutrient export values reported for the less frequently sampled monitoring studies (Isaac Creek, Van Swamp, and Pungo Lake), which were checked bi-weekly or monthly, are possibly less accurate than those reported for the high-frequency (weekly) sampling studies. Nevertheless, they can still be used to support the trends observed in the high-frequency sampling studies.

Carteret County - Carteret 7

Total annual nutrient export in outflow from the D1 watershed (a managed loblolly pine forest on ditched mineral soil) averaged 4.4 and 0.24 kg/ha for TN and TP, respectively, (Table 5.1). There was large year-to-year variation in these measurements, which were calculated for 1992 to 1996. The average annual export of dissolved inorganic N (DIN, NH_4-N + NO_3-N) averaged 2.4 kg/ha, with 95% of DIN export as NO_3-N. On an annual basis, DIN contributed a large fraction of TN export from the D1 watershed, accounting for 57% of the total for the period evaluated; annual Org-N export averaged 2.0 kg/ha or 43% of total. Seasonally, most of the DIN and TN export, respectively, occurred in winter at 1.6 and 2.5 kg/ha, accounting for 65% and 58% of the average annual total for DIN and TN. Maximum seasonal exports of N during the winter occurred with maximum seasonal outflow. Winter outflow accounted for 54% of total annual outflow (Table 3.2). Average seasonal exports of DIN and Org-N were more constant for the spring through fall seasons at 0.19 to 0.31 and 0.29 to 0.42 kg/ha, respectively, leading to nearly identical seasonal values for TN export (0.60 to 0.62 kg/ha). The seasonal export of TP was highest during the fall at 0.09 kg/ha, accounting for 39% of the annual total. TP export was next highest in the winter, when outflow was at a maximum; it was 0.08 kg/ha and contributed 33% of annual export.

Comparisons of nutrient concentrations in outflow for the three paired watersheds at the Carteret 7 study site (Fig. 2.2) indicate characteristic differences among the adjacent study blocks (Amatya et al., 1998; Smith, 1994). For the pre-treatment period (1988 to 1990) during which outlet weir depth was identical among the study blocks, seasonal and annual nutrient concentrations for D1, and hence nutrient exports, were found to differ from those for D2 and D3. Nutrient exports from D2 and D3 were estimated by taking into account both small hydrologic differences (91 to 96% of D1) and larger nutrient concentrations (25 to 138% of D1). Mean outflow and nutrient concentration values used to estimate exports from D2 and D3 were taken from Table 2 of Amatya et al. (1998) based on data collected during 1988 to 1990. For the three watersheds, predicted TN export from D2 (2.8 kg/ha) and D3 (1.4 kg/ha) were considerably lower than exports from D1 for the 1992 to 1996 study period.

Table 5.1. Mean nutrient export (kg/ha) in outflow from D1 watershed at Carteret 7 by quarter and year. Export values were obtained from D. M. Amatya at NC State University for January 1992 through May 1994 (see Amatya et al., 1998) and for 1995 to 1996. The annual total is the sum of quarterly values.

Quarter/Year	NH_4-N	NO_3-N	ORG-N	TN	TP
Quarterly Exports					
Winter	0.07	1.55	0.92	2.53	0.08
Spring	0.02	0.29	0.29	0.60	0.02
Summer	0.03	0.16	0.42	0.61	0.05
Fall	0.01	0.26	0.35	0.62	0.09
Annual Total	**0.13**	**2.25**	**1.99**	**4.37**	**0.24**
Annual Exports					
1992	0.08	3.75	1.68	5.52	0.13
1993	0.02	2.61	1.74	4.37	0.04
1995	0.17	1.03	1.32	2.51	0.23
1996	0.17	2.10	2.77	5.04	0.52
Mean Year	**0.11**	**2.37**	**1.88**	**4.36**	**0.23**

Export of NO_3-N accounted for 39% (D3) to 53% (D2) of TN export compared with 54% for D1; export of Org-N from D3 was 0.7 kg/ha/yr compared with an average NO_3-N export of 0.5 kg/ha/yr. In contrast to the lower exports of N fractions from D2 and D3, estimated TP exports were 0.28 to 0.29 kg/ha/yr compared with 0.24 kg/ha/yr from D1.

Carteret County - Isaac Creek

The mean TN exports estimated in outflow from managed forest blocks (ABC, B, and D) and a natural forest block (UD) at the Isaac Creek site were similar among monitoring locations (2.8 to 3.8 kg/ha/yr) (Table 5.2) despite differences in soil type. ABC and D were on mostly mineral ditched soils while block B was on ditched organic soils and block UD was on unditched organic soils. Export of TN from all blocks was highest during the winter quarter when outflow is generally highest (Table 3.3). Annual exports of DIN from the forest blocks were low at all locations at 0.04 to 0.4 for NO_3-N and 0.19 to 0.41 kg/ha for NH_4-N (Table 5.2). One difference among stands was a lack of NO_3-N export from the organic muck soils on blocks B and UD. Considerable variation in DIN output (cv =0.25 to 0.67) occurred among years associated with interannual variations in rainfall (outflow cv = 0.22 to 0.29, Table 3.3) and nutrient concentrations (Lebo and Herrmann, 1998). For P fractions, annual TP export was low from all gauged areas but higher from the managed forest stands (0.28 to 0.34 kg/ha) compared with block UD (0.11 kg/ha) (Table 5.2). Calculation of average nutrient exports for block UD, based on average outflows and nutrient concentrations, had little effect on annual values but increased the relative seasonal contributions of the spring and fall quarters to average annual export.

Average nutrient exports for block UD adjacent to the Isaac Creek watershed were estimated for the entire study from average concentrations and mean seasonal flows from 1986 to 1995. Because there were only three years with both outflow and nutrient data, average nutrient exports for the entire study period were estimated by season for average hydrological conditions to provide a comparison with exports from the 1986 to 1988 period. Nutrient concentrations used in the calculations were the average of mean values for each of the two study periods (1985 to 1988 and 1995 to 1996). A comparison of outflows during 1986 to 1988 with the entire study indicates summer outflow was 68% higher than the study mean, while spring and fall values were 48% and 88% lower than the study mean, respectively, (Table 3.4). Differences in

Table 5.2. Mean nutrient exports (kg/ha) in outflow from Isaac Creek watershed by quarter and site. Years affected by harvesting and replanting were omitted from the calculation of averages. Exports from block UD were calculated using data from 1986 to 1988 and estimated using seasonal mean concentration and outflows (see below).

Quarter/ Year	NH_4-N	NO_3-N	ORG-N	TN	PO_4-P	TP
ABC Outlet						
Winter	0.14	0.10	1.19	1.42	0.073	0.13
Spring	0.04	0.02	0.37	0.42	0.030	0.07
Summer	0.06	0.04	0.79	0.89	0.022	0.06
Fall	0.17	0.08	0.33	0.58	0.026	0.07
Annual Total	**0.41**	**0.27**	**2.63**	**3.31**	**0.151**	**0.33**
D Outlet						
Winter	0.08	0.14	1.25	1.47	0.063	0.10
Spring	0.04	0.09	0.59	0.72	0.033	0.08
Summer	0.09	0.13	0.74	0.95	0.019	0.04
Fall	0.03	0.03	0.54	0.60	0.019	0.06
Annual Total	**0.24**	**0.39**	**3.11**	**3.74**	**0.133**	**0.28**
Block B						
Winter	0.11	0.08	1.58	1.77	0.088	0.13
Spring	0.04	0.01	0.36	0.41	0.023	0.06
Summer	0.08	0.02	1.08	1.18	0.044	0.10
Fall	0.01	0.01	0.45	0.48	0.010	0.06
Annual Total	**0.25**	**0.12**	**3.46**	**3.83**	**0.165**	**0.34**
Block UD (1986-1988)						
Winter	0.23	0.03	1.52	1.78	0.024	0.07
Spring	0.06	0.00	0.25	0.31	0.010	0.02
Summer	0.03	0.01	0.77	0.82	0.012	0.03
Fall	0.00	0.00	0.00	0.00	0.000	0.00
Annual Total	**0.33**	**0.04**	**2.55**	**2.91**	**0.045**	**0.11**
Block UD (Mean Conditions[1])						
Winter	0.07	0.02	1.08	1.17	0.014	0.04
Spring	0.07	0.01	0.35	0.42	0.010	0.02
Summer	0.03	0.01	0.70	0.75	0.010	0.02
Fall	0.01	0.01	0.45	0.47	0.005	0.02
Annual Total	**0.19**	**0.05**	**2.58**	**2.81**	**0.039**	**0.10**

Notes: (1) Water quality data are from 1985 to 1988 and 1995 to 1996; seasonal outflow data are from 1986 to 1995.

Table 5.3. Mean nutrient export (kg/ha) in outflow from Jones 5 watershed for 1981 to 1984. The annual total is the sum of seasonal values.

Quarter/Year	NH_4-N	NO_3-N	ORG-N	TN	TP
Quarterly Exports					
Winter	0.48	0.22	2.52	3.21	0.09
Spring	0.04	0.01	0.49	0.53	0.01
Summer	0.02	0.00	0.28	0.31	0.02
Fall	0.11	0.00	0.31	0.42	0.01
Annual Total	**0.65**	**0.23**	**3.60**	**4.48**	**0.13**

the seasonal distributions of nutrient exports between 1986 and 1988 and mean conditions (Table 5.2) can largely be attributed to deviations in flow.

Jones County - Jones 5

Mean nutrient export in outflow from the Jones 5 research stands (managed loblolly pine forest on ditched mineral soil) occurred largely during winter months (Table 5.3), as observed at the Carteret County sites. Winter export of DIN and TN was 0.70 and 3.2 kg/ha, respectively, accounting for 75 and 72%, respectively, of average annual values for each fraction. The large contribution of winter export to annual totals for N fractions at this site can be attributed to seasonally maximum outflow and nitrogen concentrations during winter (see Tables 3.5 and 4.4). On an annual basis, DIN accounted for 16% of TN export, with the majority of DIN contributed by NH_4-N. The remaining 84% of TN export occurred as dissolved and particulate components of Org-N. The annual TP export from the site was low at 0.13 kg/ha for the study period. As with the N fractions, winter TP export accounted for most (63%) of the annual total, consistent with the seasonal flow distribution; winter outflow accounted for 62% of annual outflow.

Table 5.4. Mean nutrient exports (kg/ha) in outflow from the Tyrrell County watersheds by quarter and site.

Quarter/Year	NH_4-N	NO_3-N	ORG-N	TN	TP
T102 Mineral Soil					
Winter	0.13	0.17	1.23	1.53	0.055
Spring	0.06	0.06	1.12	1.25	0.046
Summer	0.05	0.03	0.43	0.52	0.019
Fall	0.06	0.12	0.42	0.60	0.050
Annual Total	**0.31**	**0.38**	**3.19**	**3.89**	**0.17**
T104 Deep Organic Soil					
Winter	0.15	0.12	2.19	2.45	0.099
Spring	0.16	0.02	1.40	1.58	0.074
Summer	0.05	0.01	1.01	1.07	0.081
Fall	0.07	0.02	1.29	1.39	0.045
Annual Total	**0.43**	**0.17**	**5.89**	**6.50**	**0.30**
T107 Shallow Organic Soil					
Winter	0.27	0.10	2.20	2.57	0.137
Spring	0.10	0.04	0.87	1.01	0.020
Summer	0.05	0.02	0.72	0.79	0.044
Fall	0.12	0.06	1.39	1.58	0.026
Annual Total	**0.55**	**0.22**	**5.17**	**5.94**	**0.23**

Tyrrell County

Mean concentrations and exports of DIN in outflow from the three undeveloped sites in the Tyrrell County study were generally low (Table 5.4), with NO_3-N and NH_4-N concentrations typically less than 0.1 mg/L. Export of DIN from the natural sites during the study ranged from 0.60 to 0.77 kg/ha/yr compared with an average annual TN export of 3.9 kg/ha (T102, on ditched mineral soil), 5.9 kg/ha (T107, on ditched shallow organic soil), and 6.5 kg/ha (T104, on unditched deep organic soil). The majority of TN export (72 to 87%) occurred as dissolved and particulate components of Org-N. For phosphorus, similar TP concentrations among the three soil types monitored (Table 4.5) contributed to similar annual TP export levels of 0.17 to 0.30 kg/ha (Table 5.4), with a greater export off the organic soils.

The highest nutrient exports occurred in the winter concurrent with highest outflows (e.g., Table 3.6). However, lower winter nutrient concentrations (Table 4.5) partially offset higher outflows, so winter contributions to annual nutrient exports were generally lower than the corresponding contribution of winter outflow to annual outflow (Table 5.4). For example, the winter quarter accounted for 39, 38, and 43% of TN export from T102, T104, and T107, respectively, compared with 54, 42, and 49% of total outflow. Lowest nutrient exports generally occurred in the summer when outflow was at its lowest. The relative contribution of DIN to TN was only 6% (deep organic) to 16% (mineral) in the summer compared to 11 and 20%, respectively, during the winter. TP export was more evenly distributed across seasons for the mineral and deep organic soils compared to TP export from the shallow organic site, where a disproportionate amount of TP export occurred in the winter. This high TP export from the shallow organic site during the winter can be attributed to higher outflow and an intermediate TP concentration (see Table 4.5).

Washington County

The majority of annual export of several nutrient fractions in outflow from the natural forest site on unditched mineral soil in Washington County occurred during the winter (Table 5.5). The winter quarter accounted for 92% of NO_3-N and 60% of TP annual export, concurrent with 64.6% of annual outflow (see Table 3.7). The predominant contribution of winter NO_3-N export to the annual total can be attributed to high concentration values (Table 4.6) and maximum outflow (Table 3.7) during the winter quarter. For NH_4-N and Org-N, summer increases in the concentration of both fractions contributed to summer and winter peaks in export. The annual TN export from the site was 2.3 kg/ha, on average, and varied between 0.9 and 4.5 kg/ha for different study years due to variations in total outflow (Table 3.7). Overall, DIN export was mainly NH_4-N (84%).

Parker Tract

Mean nitrogen exports measured in outflow from blocks at the Parker Tract were very high for forested land. TN export from the block with organic soil (F6) was highest for all sites surveyed in this report, with an average annual export of 23.9 kg/ha (Table 5.6). In comparison, the TN export from the block with mineral soil (F3) was lower and more similar to the exports from other study sites, with an annual export of 6.6 kg/ha. Both of these blocks were managed loblolly pine forest on ditched soil. The S4 outlet, with drainage from blocks with both mineral and organic ditched soil, exported 17.4 kg/ha/yr of TN. The blocks draining to the S4 outlet are mostly managed stands and about one-third natural stands. Most of the TN export from the monitoring locations with reliable measured outflow (and presumably all locations) occurred during the winter quarter due to the high volume of runoff that occurred during those months (Table 3.8). Average annual TN export during the study period was also high during the summer and fall quarters due to several large tropical storms during 1996 to 1998. For the block with organic soil, most of the nitrogen occurred as Org-N (58%), while most of the TN from the mineral soil block occurred as NO_3-N (72%) (Table 5.6). TP export from the organic soil block was higher at 0.36 kg/ha than from the managed forest block on mineral soil (0.06 kg/ha).

The distribution of forms and total export of nitrogen from the S4 watershed reflected the mixture of mineral and organic soil present on the watershed (Table 5.6). The export of TN (17.4 kg/ha) was between that of the

Table 5.5. Mean nutrient export (kg/ha) in outflow from the forested wetland site in Washington County by quarter and year. Exports were calculated by calendar and study year.

Quarter/ Year	NH_4-N	NO_3-N	ORG-N	TN	PO_4-P	TP
Quarterly Exports						
Winter	0.13	0.05	0.94	1.13	0.001	0.07
Spring	0.06	0.00	0.33	0.39	0.002	0.01
Summer	0.13	0.00	0.65	0.78	0.002	0.03
Fall	0.00	0.00	0.01	0.01	0.000	0.00
Annual Total	**0.31**	**0.06**	**1.92**	**2.30**	**0.004**	**0.12**
1/94 to 12/94	0.12	0.11	0.68	0.91	0.000	0.02
1/95 to 12/95	0.37	0.05	1.87	2.29	0.012	0.20
10/93 to 9/94	0.12	0.11	0.68	0.90	0.000	0.02
10/94 to 9/95	0.37	0.05	1.86	2.29	0.012	0.20
10/95 to 9/96	0.58	0.02	3.88	4.47	0.000	0.17

Table 5.6. Mean nutrient exports (kg/ha) in outflow from the Parker Tract watersheds by quarter and site. Soil types are: (F3) mineral; (F6) organic; and (S4) mineral and organic.

Quarter/Year	NH_4-N	NO_3-N	ORG-N	TN	TP
Block F3					
Winter	0.36	1.93	0.52	2.81	0.035
Spring	0.05	0.35	0.15	0.55	0.005
Summer	0.06	0.36	0.11	0.52	0.002
Fall	0.20	2.11	0.39	2.70	0.013
Annual Total	**0.67**	**4.74**	**1.16**	**6.57**	**0.06**
Block F6					
Winter	0.12	3.15	5.29	8.55	0.094
Spring	0.17	1.12	2.12	3.41	0.052
Summer	0.22	2.09	3.21	5.53	0.080
Fall	0.22	2.95	3.21	6.38	0.134
Annual Total	**0.73**	**9.32**	**13.82**	**23.87**	**0.36**
S4 Outlet					
Winter	0.57	6.04	3.44	10.05	0.035
Spring	0.19	0.70	0.82	1.71	0.013
Summer	0.16	1.35	1.03	2.54	0.011
Fall	0.13	1.45	1.48	3.07	0.018
Annual Total	**1.05**	**9.54**	**6.77**	**17.37**	**0.08**

organic (F6) and mineral (F3) blocks, as was the export of Org-N (6.8 kg/ha). The export of both NO_3-N (9.5 kg/ha) and NH_4-N (1.05 kg/ha) was slightly higher at the S4 outlet than in drainage from the organic soil block, suggesting that reported nutrient exports at the two locations listed in Table 5.6 do not adequately represent the entire watershed. Export of TP through the S4 outlet was low at 0.08 kg/ha.

Table 5.7. Mean nutrient exports (kg/ha) in outflow from the Van Swamp watershed by quarter and year.

Quarter/Year	NH_4-N	NO_3-N	ORG-N	TN	TP
Van Swamp (1985-1987)					
Winter	0.11	1.11	0.92	2.15	0.045
Spring	0.30	0.17	0.56	1.03	0.022
Summer	0.46	0.64	0.65	1.76	0.067
Fall	0.19	0.30	0.53	1.02	0.011
Annual Total	**1.06**	**2.22**	**2.66**	**5.96**	**0.146**
Van Swamp 1993-1995					
Winter	0.20	4.46	2.98	7.65	0.123
Spring	0.17	0.18	0.77	1.12	0.011
Summer	0.04	0.00	0.09	0.15	0.000
Fall	0.02	0.01	0.15	0.18	0.000
Annual Total	**0.44**	**4.65**	**3.99**	**9.09**	**0.135**
Mean for Study Periods					
Winter	0.16	2.79	1.95	4.90	0.08
Spring	0.24	0.17	0.67	1.08	0.02
Summer	0.25	0.32	0.37	0.95	0.03
Fall	0.11	0.16	0.34	0.60	0.01
Annual Total	**0.75**	**3.44**	**3.32**	**7.53**	**0.14**

Van Swamp and Pungo Lake

The mean export of TN in outflow from the Van Swamp site was higher than the export from most of the other studies except for the Parker Tract. The Van Swamp watershed included nearly equal areas of managed forest stands and natural stands. The soils were a combination of mineral and organic soils; some were ditched and some were not. Annual TN export averaged 7.5 kg/ha for the two periods 1985 to 1987 and 1993 to 1995 monitored by the U.S. Geological Survey (Table 5.7). For TN export, DIN contributed 4.2 kg/ha (54%) to the average annual total export compared to 3.3 kg/ha for Org-N. Most of DIN exported (81%) was as NO_3-N (3.4 kg/ha), with NH_4-N contributing 0.8 kg/ha to annual export. TP export from Van Swamp was low at 0.14 kg/ha. Seasonally, the winter quarter contributed most of the annual total for TN, Org-N, NO_3-N, and TP, while the highest export of NH_4-N occurred in the summer. For the 1993 to 1995 period, 84% of the TN export, 75% of the Org-N export, 96% of the NO_3-N export, and 92% of the TP export occurred in the winter quarter when most of the runoff occurred (Table 3.9). In the 1985 to 1987 monitoring period, summer storms contributed a large fraction of annual rainfall while winters were relatively dry. Consequently, the winter quarter only contributed 36% of the TN export, 35% of the Org-N export, 50% of the NO_3-N export, and 31% of the TP export for the 1985 to 1987 monitoring period.

Annual TN export from the Pungo Lake site was also high (6.1 kg/ha) compared with many of the other sites (Table 5.8). The Pungo Lake site was a natural forest on unditched organic soil. Very little of the TN export was in the form of NO_3-N (0.08 kg/ha). Although NH_4-N was not measured, it is unlikely that NH_4-N export was greater than 1 kg/ha based on data from the other sites. Therefore, it is likely that most of TN exported occurred as dissolved and particulate forms of Org-N. This would be expected from the deep organic soils at Pungo Lake. Annual TP export from Pungo Lake was 0.13 kg/ha.

Summary of Nutrient Exports

Nutrient exports from the forested lands reviewed in this study were generally low with the exception of the nitrogen exports from the Parker Tract (Table 5.9; Figs. 5.1 and 5.2). TN exports from 75% of the study sites were less than 6.5 kg/ha/yr, while the highest annual TN

Table 5.8. Mean nutrient exports (kg/ha) in outflow from the Pungo Lake site by quarter and year.

Quarter/Year	NH_4-N	NO_3-N	ORG-N	TN	TP
Quarterly Exports					
Winter	N/A*	0.04	N/A*	2.74	0.045
Spring	N/A	0.02	N/A	2.54	0.056
Summer	N/A	0.01	N/A	0.22	0.011
Fall	N/A	0.00	N/A	0.62	0.022
Annual Total	**N/A**	**0.08**	**N/A**	**6.12**	**0.135**

* Not measured.

Table 5.9. Average quarterly and annual exports (kg/ha) in outflow from research study sites.

Site	*Winter*	*Spring*	*Summer*	*Fall*	*Annual*	*Winter*	*Spring*	*Summer*	*Fall*	*Annual*
	NO_3-N					**NH_4-N**				
D1	1.55	0.29	0.16	0.26	2.25	0.07	0.02	0.03	0.01	0.13
B	0.08	0.01	0.02	0.01	0.12	0.11	0.04	0.08	0.01	0.25
D	0.14	0.09	0.13	0.03	0.39	0.08	0.04	0.09	0.03	0.24
UD	0.02	0.01	0.01	0.01	0.05	0.07	0.07	0.03	0.01	0.19
J5	0.22	0.01	0.00	0.00	0.23	0.48	0.04	0.02	0.11	0.65
T102	0.17	0.06	0.03	0.12	0.38	0.13	0.06	0.05	0.06	0.31
T104	0.12	0.02	0.01	0.02	0.17	0.15	0.16	0.05	0.07	0.43
T107	0.10	0.04	0.02	0.06	0.22	0.27	0.10	0.05	0.12	0.55
W1	0.05	0.00	0.00	0.00	0.06	0.13	0.06	0.13	0.00	0.31
F3	1.93	0.35	0.36	2.11	4.74	0.36	0.05	0.06	0.20	0.67
F6	3.15	1.12	2.09	2.95	9.32	0.12	0.17	0.22	0.22	0.73
VANS	2.79	0.17	0.32	0.16	3.44	0.16	0.24	0.25	0.11	0.75
PL	0.04	0.02	0.01	0.00	0.07	N/A	N/A	N/A	N/A	N/A
ABC*	0.10	0.02	0.04	0.08	0.27	0.14	0.04	0.06	0.17	0.41
S4*	6.04	0.70	1.35	1.45	9.54	0.57	0.19	0.16	0.13	1.05

Site	*Winter*	*Spring*	*Summer*	*Fall*	*Annual*	*Winter*	*Spring*	*Summer*	*Fall*	*Annual*
	DIN					**Org-N**				
D1	1.61	0.31	0.19	0.27	2.38	0.92	0.29	0.42	0.35	1.99
B	0.19	0.05	0.10	0.03	0.37	1.58	0.36	1.08	0.45	3.46
D	0.22	0.13	0.22	0.06	0.63	1.25	0.59	0.74	0.54	3.11
UD	0.09	0.08	0.04	0.02	0.19	1.08	0.35	0.70	0.45	2.58
J5	0.70	0.05	0.02	0.11	0.88	2.52	0.49	0.28	0.31	3.60
T102	0.30	0.13	0.09	0.18	0.70	1.23	1.12	0.43	0.42	3.19
T104	0.27	0.18	0.07	0.09	0.61	2.19	1.40	1.01	1.29	5.89
T107	0.37	0.14	0.07	0.19	0.77	2.20	0.87	0.72	1.39	5.17
W1	0.18	0.06	0.13	0.00	0.37	0.94	0.33	0.65	0.01	1.92
F3	2.29	0.39	0.42	2.31	5.41	0.52	0.15	0.11	0.39	1.16
F6	3.27	1.29	2.31	3.17	10.05	5.29	2.12	3.21	3.21	13.82
VANS	2.94	0.41	0.57	0.26	4.19	1.95	0.67	0.37	0.34	3.32
PL	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ABC*	0.24	0.06	0.10	0.25	0.68	1.19	0.37	0.79	0.33	2.63
S4*	6.61	0.89	1.51	1.58	10.59	3.44	0.82	1.03	1.48	6.77

Site	*Winter*	*Spring*	*Summer*	*Fall*	*Annual*	*Winter*	*Spring*	*Summer*	*Fall*	*Annual*
	Total-N					**Total-P**				
D1	2.53	0.60	0.61	0.62	4.37	0.08	0.02	0.05	0.09	0.24
B	1.77	0.41	1.18	0.48	3.83	0.13	0.06	0.10	0.06	0.34
D	1.47	0.72	0.95	0.60	3.74	0.10	0.08	0.04	0.06	0.28
UD	1.17	0.42	0.75	0.47	2.91	0.04	0.02	0.02	0.02	0.10
J5	3.21	0.53	0.31	0.42	4.48	0.09	0.01	0.02	0.01	0.13
T102	1.53	1.25	0.52	0.60	3.89	0.05	0.05	0.02	0.05	0.17
T104	2.45	1.58	1.07	1.39	6.50	0.10	0.07	0.08	0.04	0.30
T107	2.57	1.01	0.79	1.58	5.94	0.14	0.02	0.04	0.03	0.23
W1	1.13	0.39	0.78	0.01	2.30	0.07	0.01	0.03	0.00	0.12
F3	2.81	0.55	0.52	2.70	6.57	0.03	0.00	0.00	0.01	0.06
F6	8.55	3.41	5.53	6.38	23.87	0.09	0.05	0.08	0.13	0.36
VANS	4.90	1.08	0.95	0.60	7.53	0.08	0.02	0.03	0.01	0.14
PL	2.44	2.27	0.20	0.56	5.46	0.04	0.05	0.01	0.02	0.12
ABC*	1.42	0.42	0.89	0.58	3.31	0.13	0.07	0.06	0.07	0.33
S4*	10.05	1.71	2.54	3.07	17.37	0.04	0.01	0.01	0.02	0.08

Notes: (*) Export values for watershed outlets that include other sites. Outlet values were excluded from summary statistics in Figs. 5.1 and 5.2.

export was 23.9 kg/ha from the organic soil block (F6) on the Parker Tract. Annual DIN exports were less than 2.9 kg/ha, and Org-N exports were less than 4.0 kg/ha for 75% of the forested sites. Exports of these N constituents from the Parker Tract F6 site were more than three times greater at 10.0 kg/ha/yr for DIN and 13.8 kg/ha/yr for Org-N. Annual TP export from all forested sites was less than 0.36 kg/ha.

The predominant form of N was Org-N at a majority of the monitoring locations from eastern North Carolina (10 of 14) (Table 5.9). The exceptions to this pattern were S4, D1, F3, and VANS; annual DIN export accounted for 54 to 82% of average TN export for those three sites, mainly as NO_3-N. In terms of seasonal variations, the relative distribution of Org-N and DIN did not vary much among seasons for a given site. The relative contribution of NO_3-N and NH_4-N forms to DIN varied among sites, with each the predominant contributor to DIN in approximately half of the sites. However, sites with annual DIN export of more than 1.1 kg/ha had NO_3-N as the dominant form.

Seasonal variation in outflow from the forested sites played an important role in seasonal nutrient export. For all of the study sites, maximum TN export occurred during the winter when outflow typically accounted for more than 44% (25th percentile) of the annual total. The same was true for TP export, with the exceptions of blocks D1 and F6, where TP exports were highest during the fall, and T102, where TP exports were the same in winter and fall. For the spring through fall quarters as a whole, nutrient exports did not show any consistent pattern across sites or among years. At some of the sites (e.g., Parker Tract S4 watershed), seasonal peaks in nutrient export were observed during summer or fall quarters associated with greater outflow following hurricanes and tropical storms. For other sites (Tyrrell County sites and Pungo Lake), high nutrient export occurred during the spring quarter associated with years of high spring rainfall. These variations in reported nutrient exports during the spring, summer, and fall quarters largely reflected the seasonal distribution of rainfall during the study years.

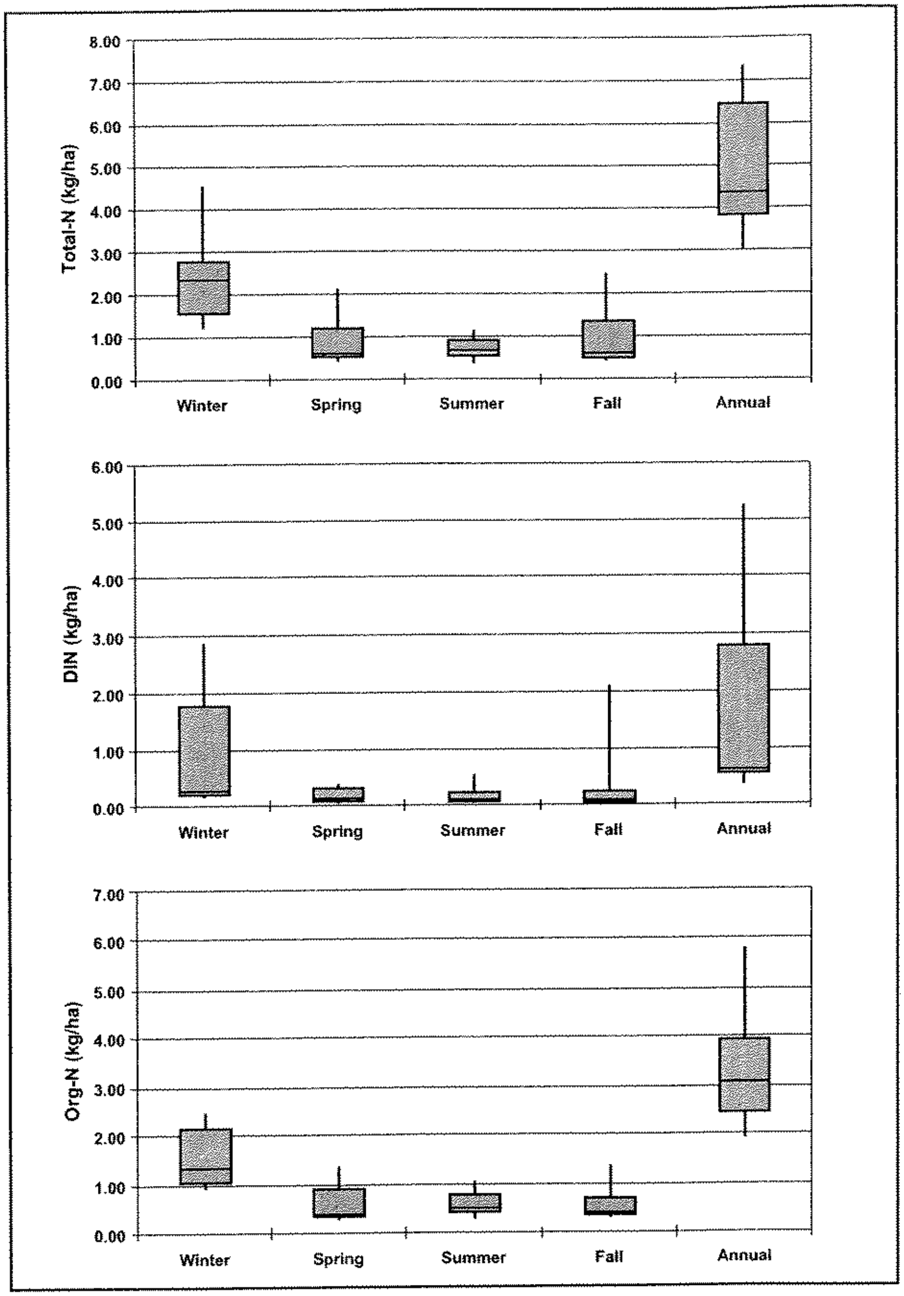


Figure 5.1. Distribution of mean seasonal exports for TN, DIN, and Org-N (see Table 5.9). The box and wisker plots show values for 10th, 25th, 75th, and 90th percentile rankings.

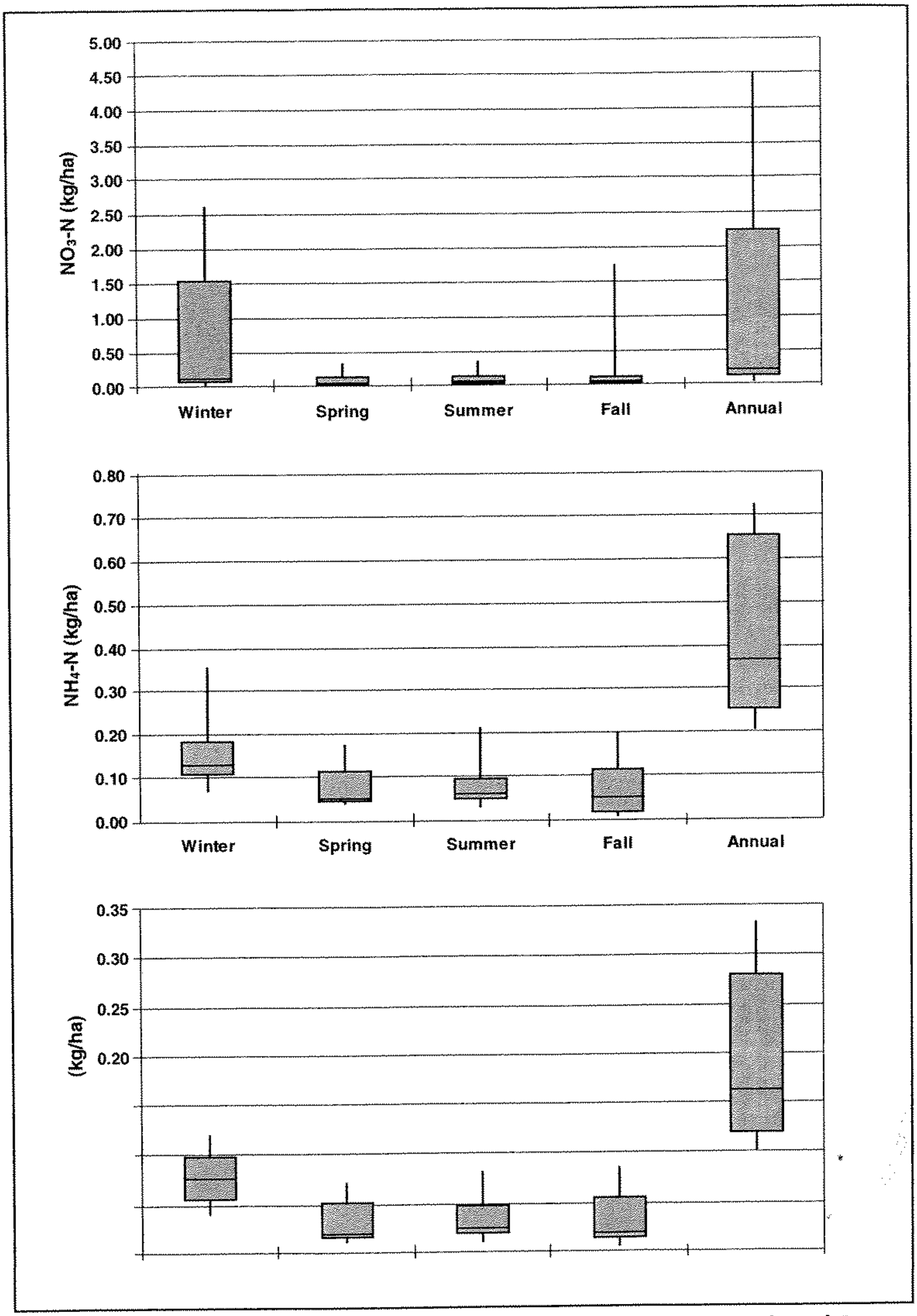


Figure 5.2. Distribution of mean seasonal exports for NO_3-N, NH_4-N, and Total-P (see Table 5.9). The box and wisker plots show values for 10th, 25th, 75th, and 90th percentile rankings.

SECTION 6 - DISCUSSION

The studies presented in this report represent a wide range of forest conditions that exist on the flat divides between coastal streams and rivers on the North Carolina coastal plain (Fig. 6.1). Thirty different soil series are represented in these studies, ranging from mineral to deep organic soils. These soils can exhibit a wide range of chemical and physical properties, which affect hydraulic conductivity and nutrient cycling. Soil hydraulic conductivities for different stands ranged from less than 1 to more than 100 cm/hr. This range of hydraulic conductivities, combined with the variety of drainage networks at many of the study sites, resulted in a wide range of drainage intensities. Other potentially important factors affecting nutrient exports were site vegetation and site location relative to dominant geological features. Among the different study sites, vegetation varied from low pocosin vegetation to mixed natural pine and hardwood stands to managed loblolly pine plantations. This range in site characteristics resulted in considerable variation in nutrient concentrations and export rates.

While differing site characteristics result in site-to-site variations, differing weather patterns can result in large seasonal and annual variations of outflow rates, nutrient concentrations, and nutrient exports across all sites. Any interpretation of reported results from individual studies, therefore, needs to be done in the context of weather patterns during the study years. The studies presented in this report covered a lengthy period of time (25 years) that represented a wide range of weather patterns. This range of weather patterns resulted in significant annual and seasonal variation in rainfall; some seasons had less than 160 mm of rainfall, reflecting drought conditions, while others had more than 640 mm in seasons that experienced two or three tropical storms or hurricanes. Since the studies reported here were conducted at different times over the past three decades, variations in weather patterns potentially confound the evaluation of outflow rates, nutrient concentrations, and nutrient exports associated with site differences.

Effects of Soil

Variations in the organic content of the soil can affect both the hydrology and nutrient export from a forested site. While the amount of organic content in soil can affect hydraulic conductivity and, thus, the subsurface drainage rate

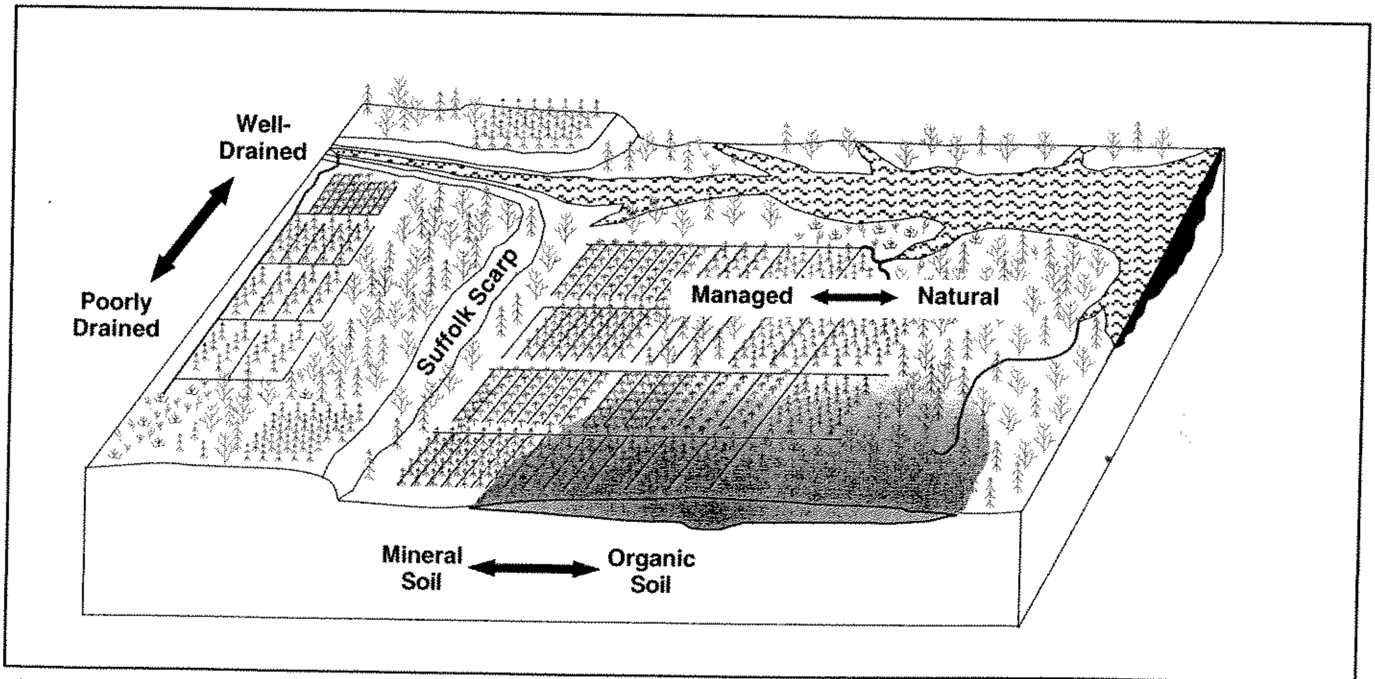


Figure 6.1. Conceptual drawing of the North Carolina coastal plain showing the range of conditions that occur in the landscape. The point shown here is that a forested site can exist anywhere along the gradients of soil organic content, drainage intensity, and forest vegetation.

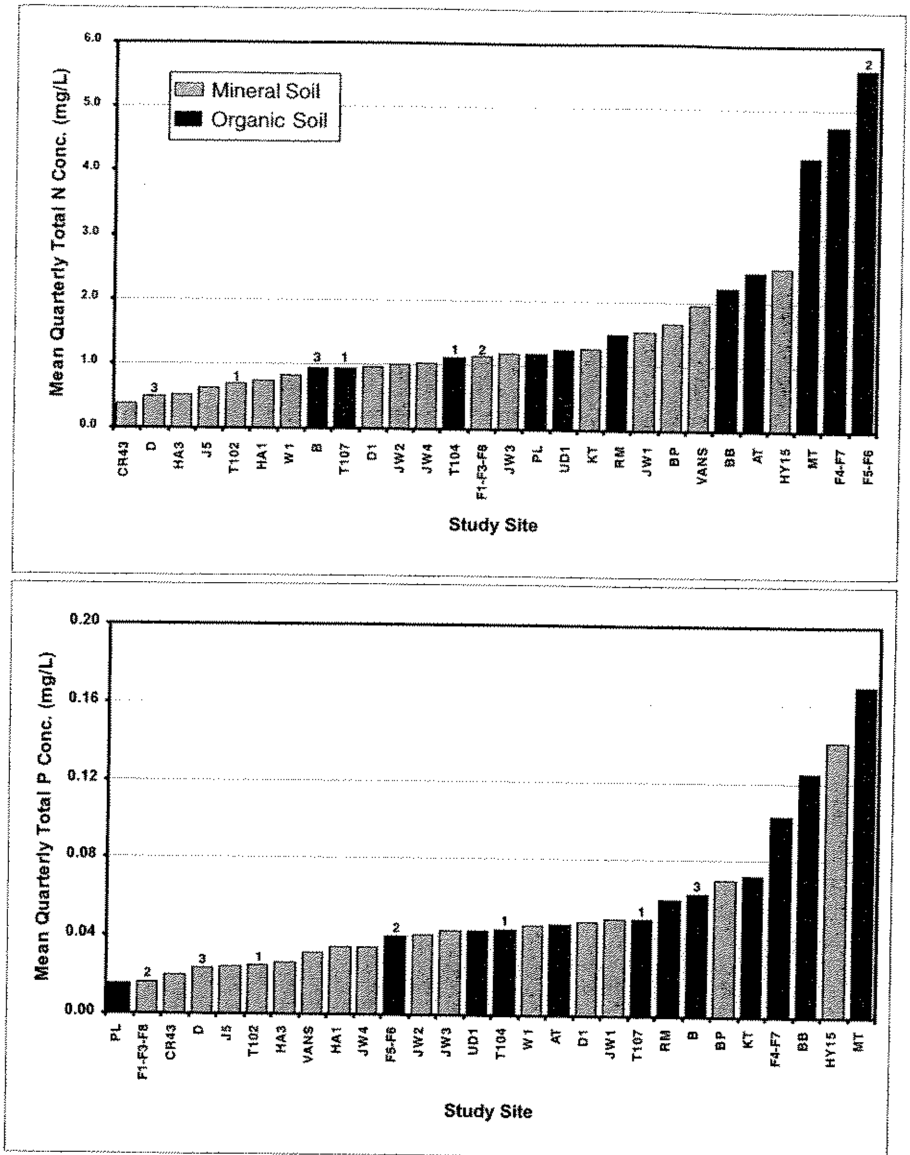


Figure 6.2. Study sites sorted by ascending mean concentrations of TN and TP in outflow during winter quarters. The sites are divided into mineral and organic soils. Numbers above the bars indicate paired sites.

and volume, other factors such as soil structure and age also greatly affect hydraulic conductivity; mineral and organic soils both can exhibit high or low conductivity. The amount of organic material in a soil has a greater potential to affect the amount and forms of nutrients exported. Two approaches were used here to evaluate the importance of a site characteristic, in this case soil organic matter, on nutrient concentrations and exports: (1) site data were grouped according to the attribute; and (2) paired watershed results were examined. An important limitation that must be considered is that variations in site characteristics are not "black and white," as grouped in our simple categorization, but rather typically occur as gradients between extremes (Fig. 6.1). For instance, some organic soils have a greater organic content than others. Evaluating the adequacy of available data to determine site effects is an essential component of the comparisons discussed.

Total nitrogen (TN) concentrations were on average higher from study plots on organic soils than from plots on mineral soils (Fig. 6.2). Five of the six highest concentrations observed during the winter quarter were from sites on organic soils; however, TN concentrations from three sites on organic soils were among the lower 50% of the sites, indicating that the presence of organic soil does not necessarily cause high TN concentrations in drainage water from forested lands. The site comparisons shown here focus on the winter period because data were available from more sites during that season. In all cases where sites were paired within a study, the highest TN concentrations came from sites on organic soils (T107,T104>T102; F5-F6>F1-F3-F8; B>D). Further, the presence of organic soils as a minor component of several tracts categorized as predominantly mineral (e.g., HY 15, VANS, and BP) may explain the relatively high winter TN concentrations observed at those sites.

Higher concentrations of TN from forests on organic soils were clearly a result of higher concentrations of Org-N draining from the organic soils (Fig. 6.3). Ten of the highest 11 Org-N concentrations observed were from sites categorized as predominantly organic soils. Further, the top four predominantly mineral sites (VANS, BP, HA1, and HY 15) had organic soils as a minor component. DIN concentrations were more variable among organic soils. Four of the six highest DIN concentrations observed were from sites with predominantly organic soils, but four of the seven lowest DIN concentrations were also categorized as organic. This variable pattern in DIN among organic soil sites indicates that net mineralization of Org-N to NH_4-N is controlled by factors other than the organic nature of the soil.

Total phosphorus (TP) concentrations during the winter season were also higher, on average, from the study plots on predominantly organic soils than from plots on mineral soils (Fig. 6.2). Four of the six highest concentrations observed were from sites categorized as organic. Examining the paired watershed comparisons in the database, as with TN, supports the general pattern of higher TP concentrations from forested watersheds with predominantly organic soils (T104, T107>T102; F5-F6>F1-F3-F8; B>D).

Effects of Drainage Intensity

The drainage characteristics of a forested site can also affect the hydrology and nutrient export from the site. The addition of field ditches improves subsurface drainage on a site; however, the amount of improvement greatly depends on the hydraulic conductivity of the soil. For instance, field ditches were present at the Parker Tract sites and at the Tyrrell County T102 and T107 sites, but the Parker Tract sites had much better subsurface drainage due to the very high hydraulic conductivities of the soil. Most of the water draining from a well-drained (often ditched) forested site will be subsurface drainage water. That is, the drainage water will travel through the soil profile to the drainage outlet. In contrast, drainage water from a poorly drained site will be through surface drainage or shallow subsurface flow. The resulting hydrologic characteristics of sites with contrasting drainage intensity are illustrated in Figure 6.4; water table depth and drainage volume are compared for a well-drained (D1) and a poorly drained (W1) forest stand. In the poorly drained forest, periods of outflow occurred when the water table rose above the soil surface (Fig. 6.4a), with water moving across the soil surface. Outflow from the well-drained site was also linked to the water table (Fig. 6.4b), but outflow began when water rose above the drain elevation for the ditch network rather than the soil surface.

The route that water takes to the drainage outlet has the potential to affect nutrient concentrations and total exports. Water that travels through the soil profile will transport soluble forms

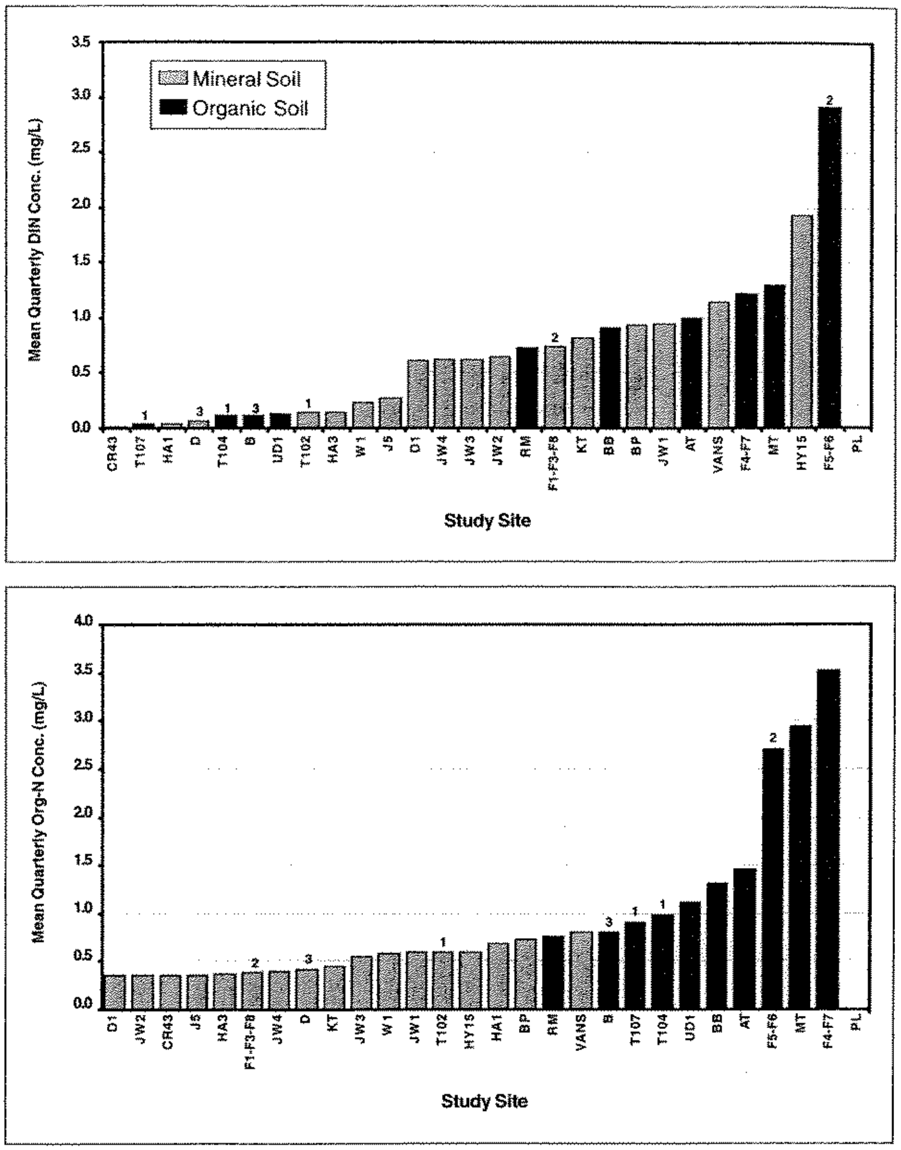


Figure 6.3. Study sites sorted by ascending mean concentrations of DIN and Org-N in outflow during winter quarters. The sites are divided into mineral and organic soils. Numbers above the bars indicate paired sites.

of nitrogen (NO_3-N, NH_4-N, and dissolved Org-N) and phosphorus (PO_4-P and dissolved Org-P), while surface flow may have a greater proportion in particulate forms. However, soluble forms of N and P may still predominate in surface outflow from the low-gradient coastal plain forests in eastern North Carolina (e.g., Lebo and Herrmann, 1998). The depth of the water in the soil profile affects the microbial processes that transform nutrients among the different forms. For example, poorly drained soils often exhibit anaerobic conditions in the soil profile, which increases the potential for denitrification. Subsurface drainage through these anaerobic zones may contain lower concentrations of TN due to NO_3-N loss or may simply maintain dissolved nitrogen as Org-N and NH_4-N.

The summary plots of winter average nutrient concentrations from all sites indicate that TN, DIN, Org-N, and TP are generally higher in outflow from drained forests compared with undrained

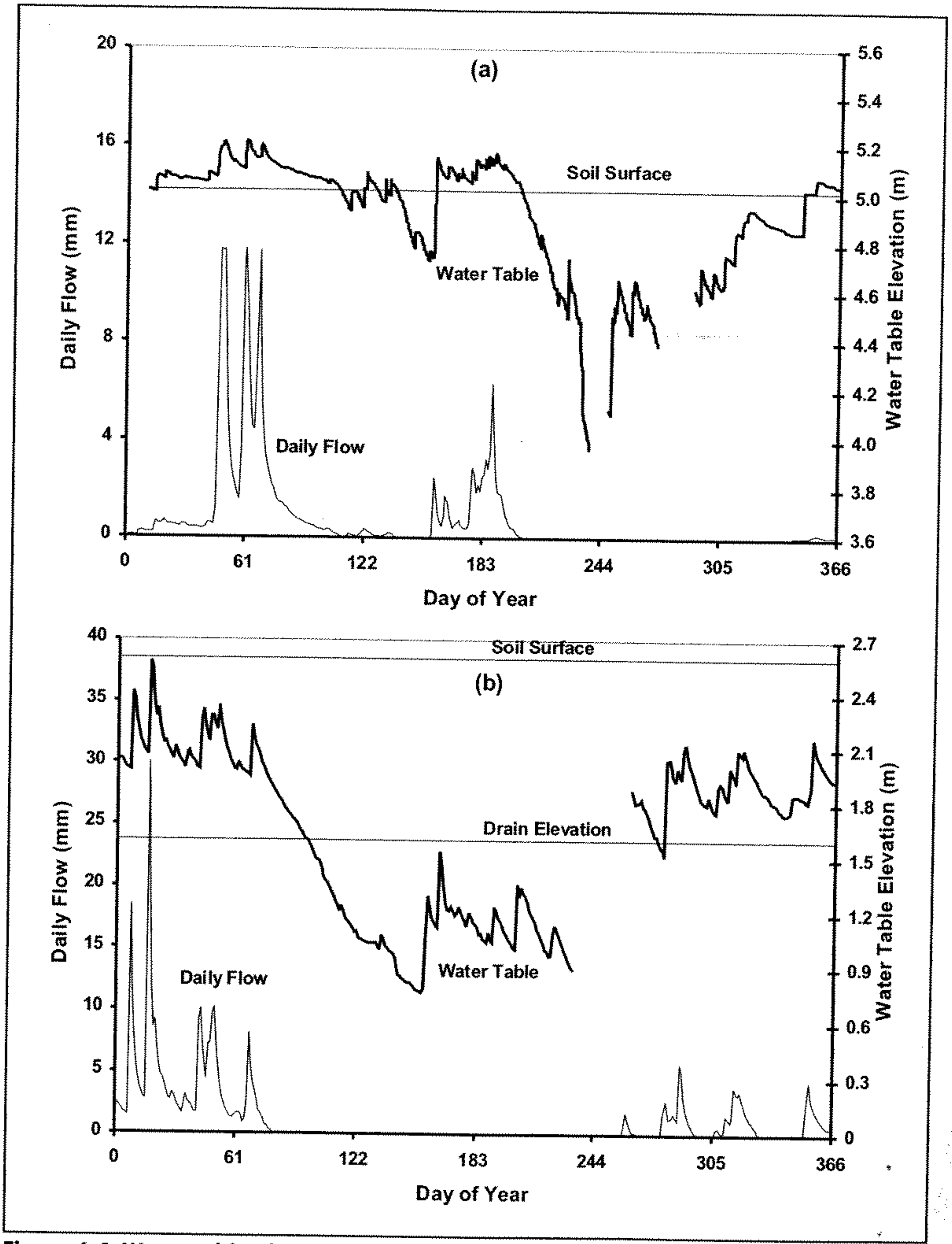


Figure 6.4. Water table elevation and daily flow rate measured at (a) the unditched Washington County site (W1) and (b) the ditched Carteret 7 site (D1) for 1995.

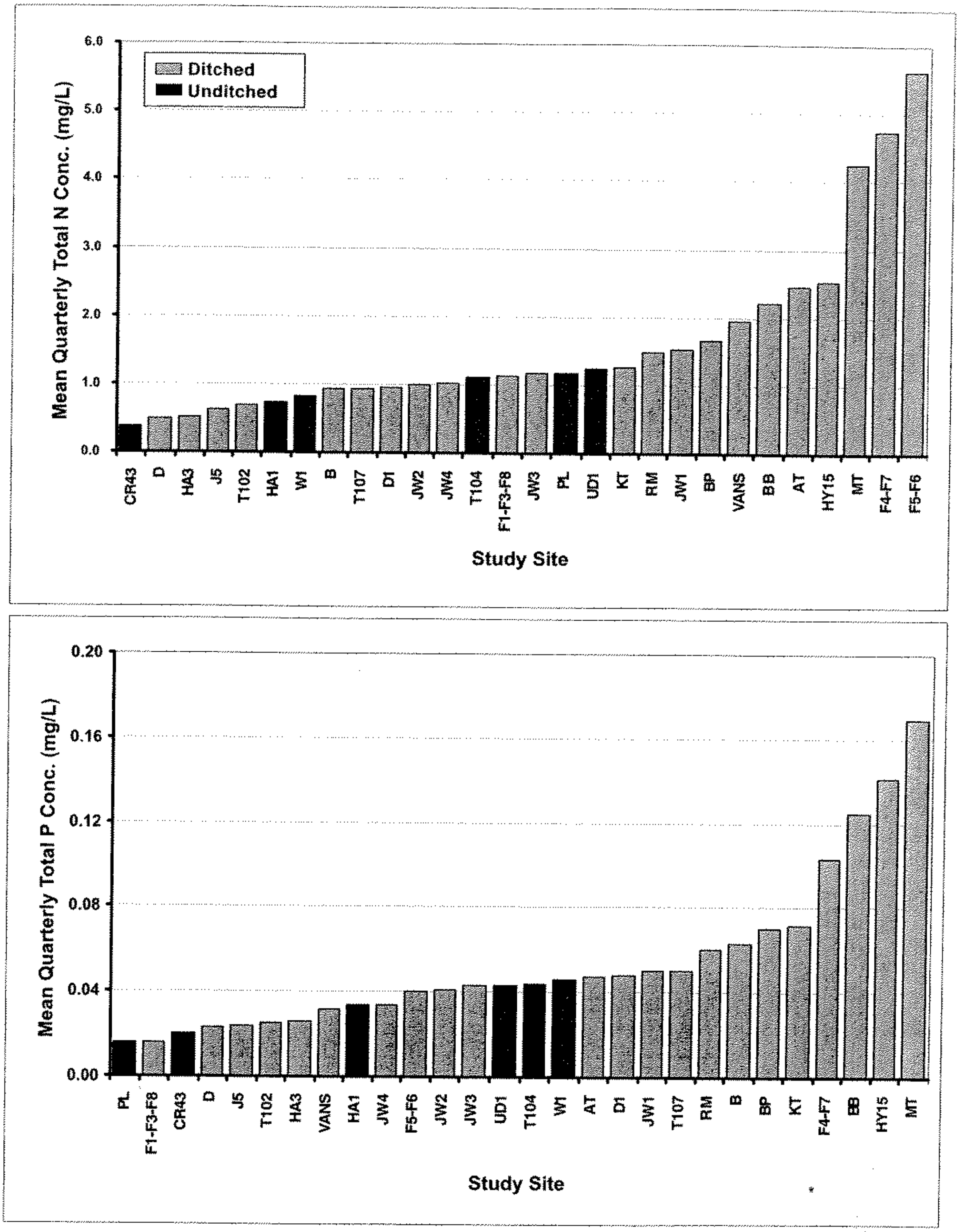


Figure 6.5. Study sites sorted by ascending mean concentrations of TN and TP in outflow during winter quarters. The sites are divided into sites that are primarily ditched and sites that are unditched.

Table 6.1. Mean annual nutrient and dissolved oxygen concentrations from subwatershed pairings of similar soil types—ditched vs. unditched. The subwatershed on the left is ditched (B, HA3, T107). Values are the mean of quarterly averages reported in Section 4 in mg/L.

	Isaac Creek Sites		***Croatan/ Craven 40***		***Tyrrell County Sites***	
Parameter	***Block B***	***Block UD***	***HA3***	***CR43***	***T107***	***T104***
NH_4-N	0.063	0.096	0.003	0.007		0.081
NO_3-N	0.021	0.020	0.070	0.021	0.041	0.027
DIN	0.083	0.116	0.073	0.028		0.11
Org-N	0.70	1.13	0.45	0.56	1.13	1.18
Total N	0.78	1.25	0.52	0.58	1.17	1.29
Total P	0.081	0.043	0.032	0.023	0.043	0.065
DO	6.04	5.65	6.40	3.83		

sites (Figs. 6.5 and 6.6). Because of the strong dependence of outflow nutrient concentrations on general soil type and the limited number of unditched sites (n=6), the general patterns suggested in Figures 6.5 and 6.6 need to be validated by paired groupings of watersheds of similar soil type.

Table 6.1 provides mean annual nutrient and dissolved oxygen concentrations for the three paired groupings of subwatersheds with similar soil types and physiographic settings. No increases in mean concentrations of DIN, TN, and TP associated with drainage systems were consistently observed for the three sets of paired subwatersheds. In fact, the TN concentration was actually consistently higher in drainage from the unditched sites. For the paired sites with dissolved oxygen (DO) measurements, DO in outflow from the unditched forest blocks was lower than from ditched sites. This finding supports a greater potential for denitrification at unditched sites due to the presumably higher water table. The results of these paired comparisons do not conclusively demonstrate that installation of drainage systems has no impact on outflow nutrient concentrations among the diverse forested physiographic settings in eastern North Carolina, but they bring into question the general pattern suggested by data from all sites. The apparent higher TN, DIN, and TP concentrations for ditched sites appear, at least in part, to be a result of general site differences across the subgrouping (ditched vs. unditched) rather than an actual effect associated with enhanced drainage intensity.

Vegetation

Variations in forest vegetation can affect the overall hydrology by modifying the evapotranspiration (ET) at the site and, hence, outflow volume downstream. For instance, younger stands or shorter, more shrubby vegetation will result in lower ET than older and taller stands; consequently,

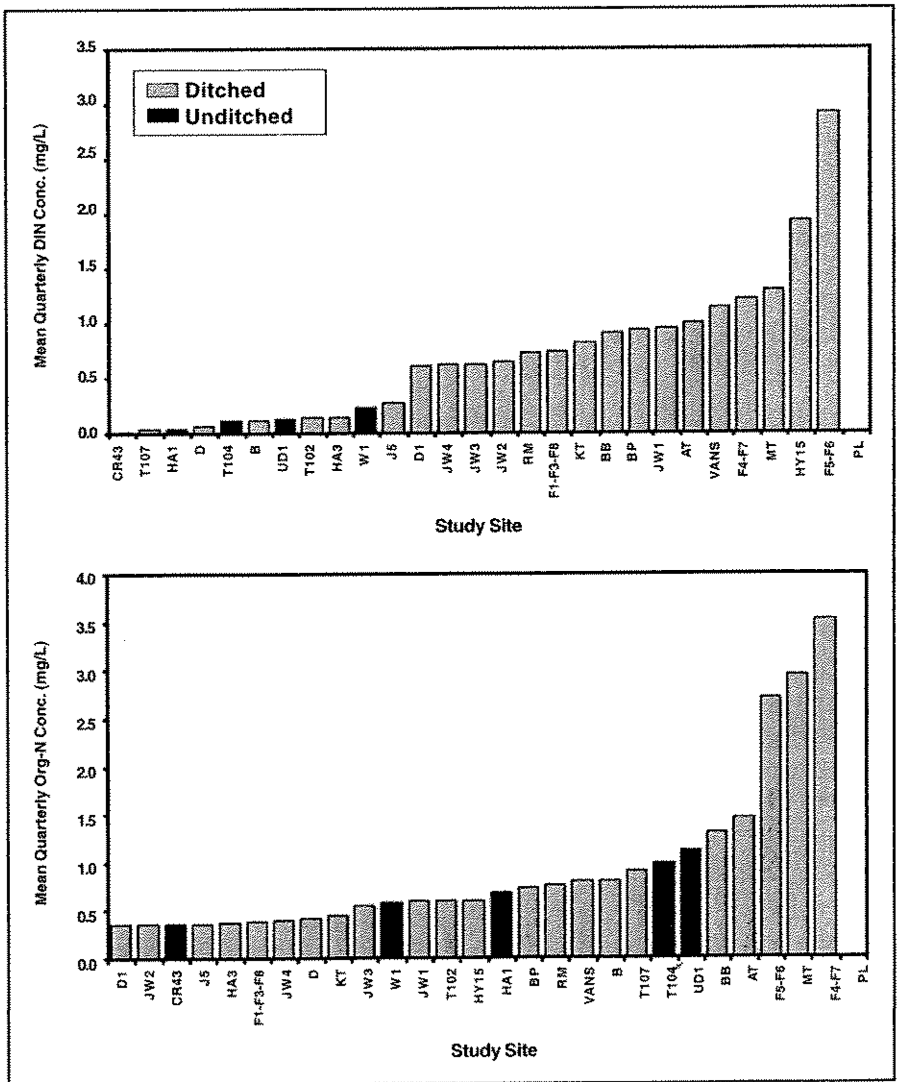


Figure 6.6. Study sites sorted by ascending mean concentrations of DIN and Org-N in outflow during winter quarters. The sites are divided into sites that are primarily ditched and sites that are unditched.

outflow volume will be higher from stands with shrubby vegetation such as T104 and T107. Also, variations in forest species could affect nutrient cycling due to differences in nutritional requirements and the seasonal water table. Differences in both biological and hydrologic processes among forest stands due to variation in vegetation have not been well quantified but are unlikely to have a large impact on nutrient export. Nutrient concentration data compiled in this study were grouped according to the dominant vegetation type (natural vs. managed pine) to evaluate whether any consistent patterns emerged. Table 6.1 also presents data that provide comparisons between paired watersheds.

For the larger database, there were differences in DIN, TN, and TP concentrations for the grouping of sites based on natural vs. pine plantation vegetation, with higher concentrations in outflow from pine plantations (Figs. 6.7 and 6.8). Mean values of TN and TP across sites were 1.73 and 0.06 mg/L, respectively, for managed pine stands compared with 1.31 and 0.04 mg/L, respectively, for natural stands. While these mean values indicate potential differences in TN and TP concentrations associated with vegetation, the differences were not significant (Student's t test) and were not supported by results from the two sets of paired watersheds (Table 6.1; UD, CR43, T104, and T107 had natural vegetation). For Org-N, there was no clear sorting of sites by vegetation type (Fig. 6.8). Because of the lack of consistency between the overall database and the two paired site comparisons, it is likely that the apparent differences are associated, at least in part, with other site factors that are not consistent across the two vegetation groupings.

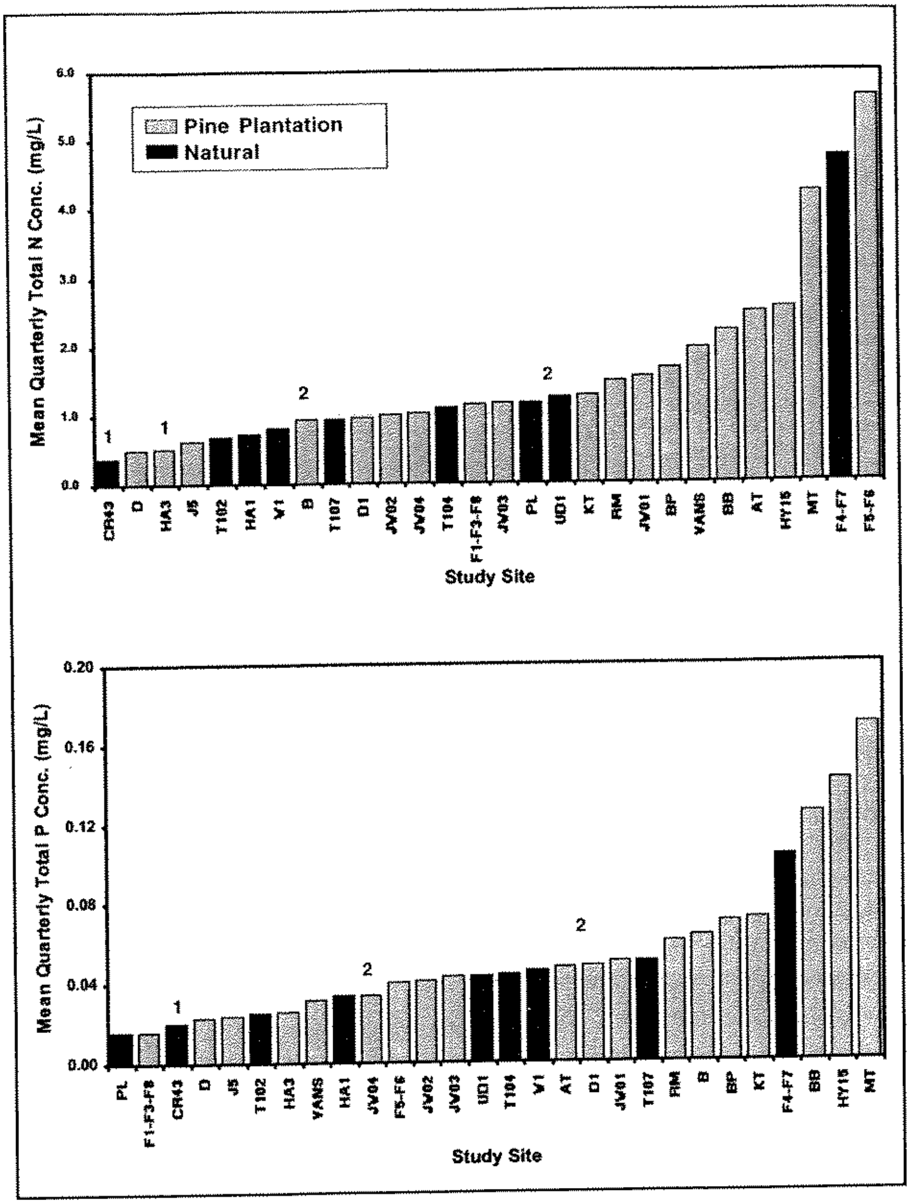


Figure 6.7. Study sites sorted by ascending mean concentrations of TN and TP in outflow during winter quarters. The sites are divided into sites that have primarily natural vegetation and sites that are pine plantations. Numbers above the bars indicate paired sites.

Physiographic Location

The location of a site on the coastal plain may affect both the hydrology and nutrient cycling from forested lands. One factor directly affected by location is average rainfall during the summer (e.g., Eder et al., 1983). As the distance of a given location from Albemarle and Pamlico sounds increases moving inland, the frequency of summertime convective storms and the likelihood of direct impacts from tropical storms decrease. Thus, sites on the outer coastal plain receive approximately 50% more rain in summer than inland locations near the piedmont do. Another physiographic factor is variation in geological formations such as the Suffolk Scarp, where prehistorical beach fronts during past ice ages helped shape the soil profile. These variations in overall site conditions may affect the drainage characteristics for the site and may partially explain differences observed in nutrient concentrations among sites.

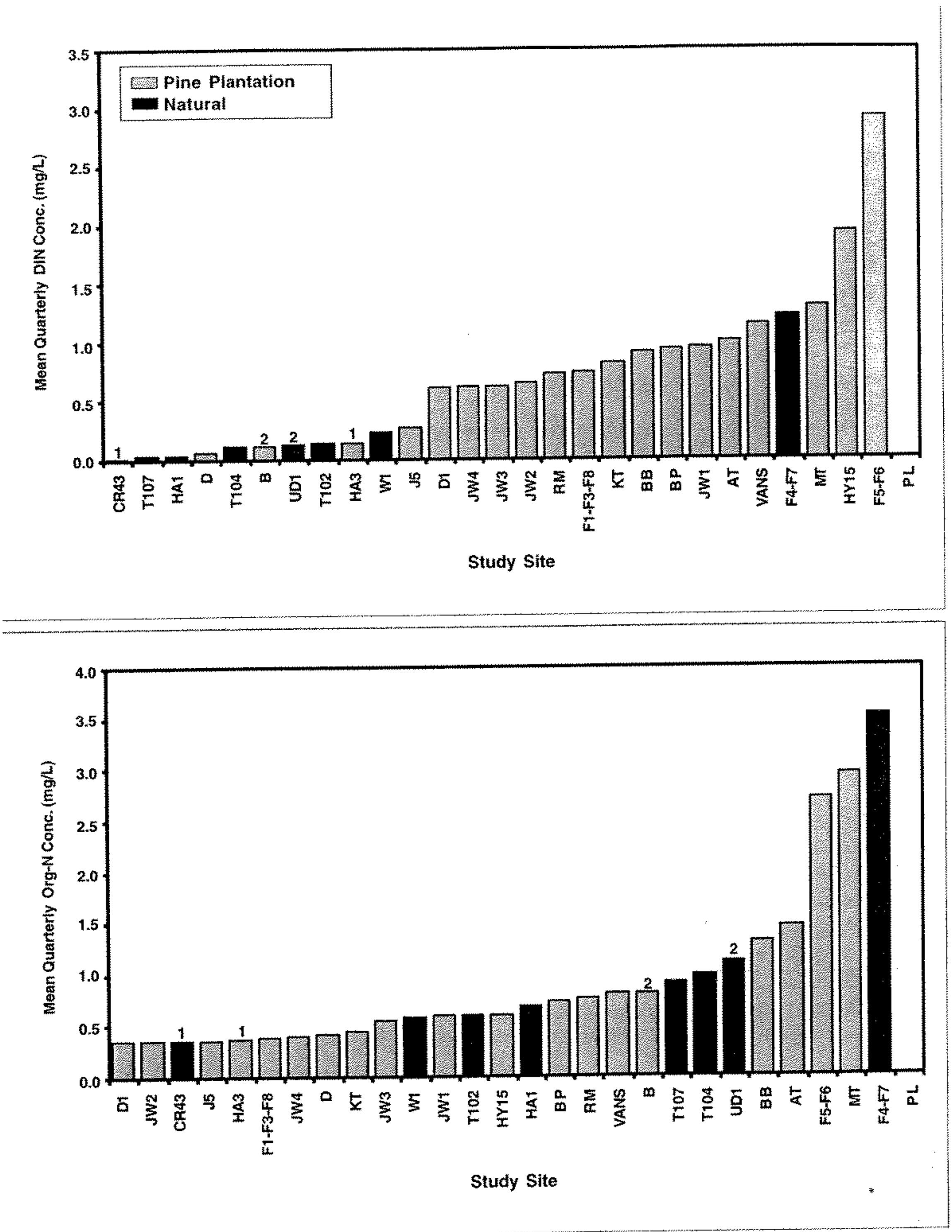


Figure 6.8. Study sites sorted by ascending mean concentrations of DIN and Org-N in outflow during winter quarters. The sites are divided into sites that have primarily natural vegetation and sites that are pine plantations. Numbers above the bars indicate paired sites.

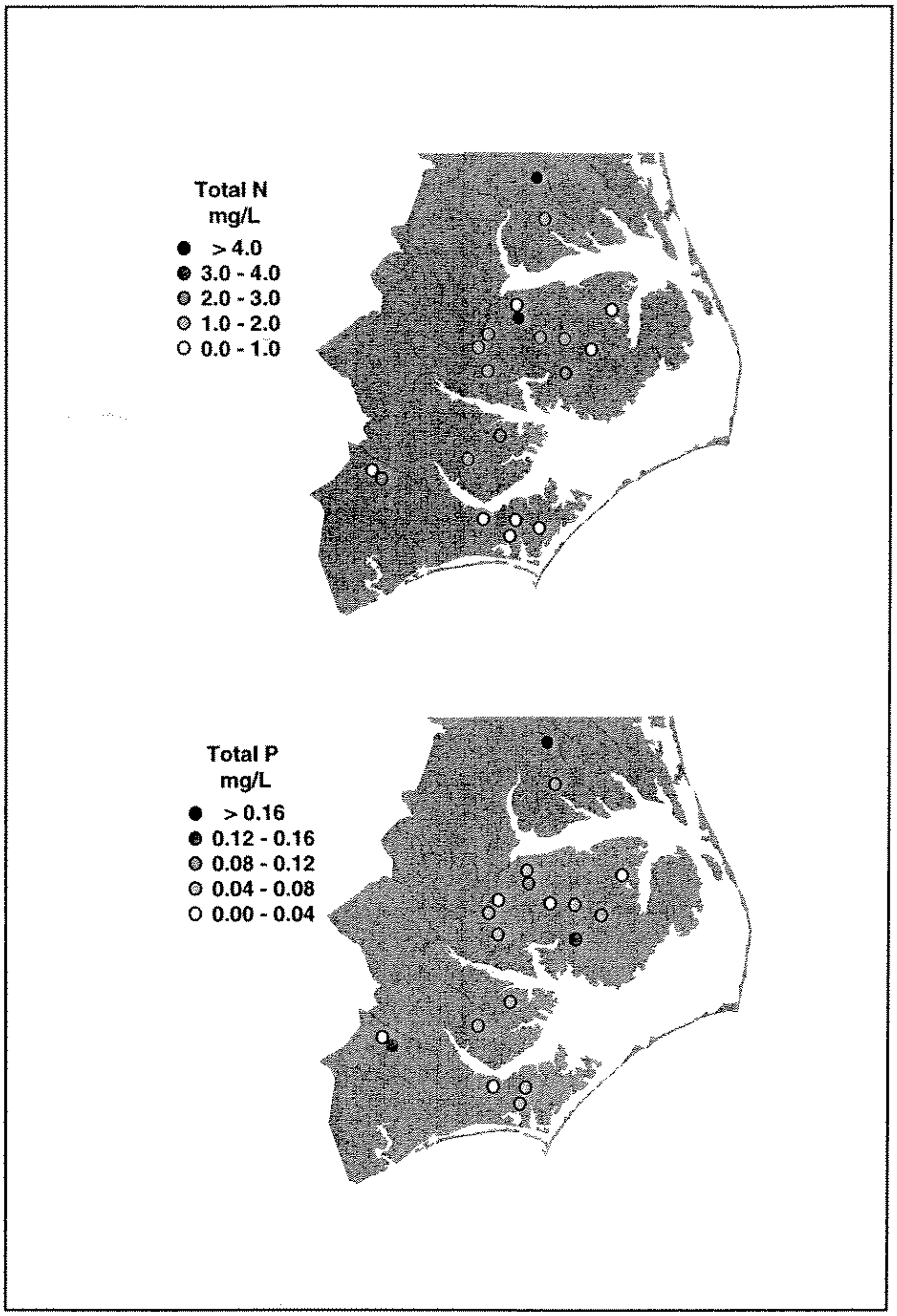


Figure 6.9. Distribution of study sites showing the mean winter quarter concentrations of TN and TP in outflow from each site.

The mean TN and TP concentrations in water draining from the forested sites compiled in this review for the winter quarter were plotted geographically to evaluate whether concentrations were related to location (Fig. 6.9). No consistent east-west or north-south gradients in nutrient concentrations were identified. A large number of sites had mean concentrations of TN and TP of less than 1 and less than 0.04 mg/L, respectively, for the winter quarter. For the Neuse River basin, five of seven locations had mean TN concentrations of less than 1 mg/L; the exceptions were Bates Bay (2.21 mg/L) and the Big Pocosin (1.65 mg/L). The same pattern of infrequently higher TN and TP concentrations during winter months was also observed in other basins in eastern North Carolina. It is notable, however, that the two sites with the highest TN concentrations (Parker and Morrison tracts) are located immediately east of the Suffolk Scarp on organic soils (see below). Overall, it appears that variation in general site characteristics, such as soil organic content, appeared to have a greater effect on nutrient concentrations across the sites than general placement in the landscape did.

The elevated TN concentrations observed at the Parker and Morrison tracts may be related to site characteristics associated with the eastern margin of the Suffolk Scarp. Elevated TN concentrations at the Parker Tract were made up of a persistent elevation of Org-N and fluctuating concentrations of NO_3-N (Figure 6.10), with peaks in NO_3-N concentration following a definite hydrological pattern. The highest concentrations of NO_3-N occurred when flow resumed after a prolonged dry period (e.g., days 500 to 700) and occurred early in the hydrograph. This pattern is consistent with a first flush phenomenon that has been described at other forested sites (Amatya et al., 1998; Schreiber et al., 1976) and is indicative of an accumulation of Org-N mineralization products in the soil during the dry period. Data from the Weyerhaeuser surveys of forested sites across eastern North Carolina during 1998 to 2000 provide evidence that the hydrologic pattern in NO_3-N concentration observed at the Parker Tract S4 outlet is typical for forest sites in the region (M. Lebo, unpubl. data), but the Parker Tract represents the extreme case for NO_3-N and TN losses. One component shared by the two sites is high drainage intensity due to the combination of drainage ditches and high soil hydraulic conductivities. These high hydraulic conductivities are likely due to surface organic soil layers overlying subsurface sand layers, presumably relics of prehistoric beach fronts. It is possible that a deeper growing-season water table at these two sites due to their well-drained condition may enhance the mineralization of soil organic matter, leading to higher concentrations of TN in drainage water. A contrasting example is the poorly drained conditions at sites T104 and T107 in Tyrrell County where much lower DIN and TN concentrations were reported (Table 4.13). Additional research needs to be done to better understand how elevated TN concentrations at the Parker and Morrison tracts may be related to drainage intensity and to identify other important site conditions not accounted for in our simple groupings (e.g., soil N content).

Nutrient Exports

The export of nutrients in forest drainage combines outflow volume and nutrient concentrations in the drainage water. In the studies reported here, contrasting spatial and temporal patterns for hydrology and nutrient concentrations emerged. It is clear from the more than 100 site years' data that most of the variation in nutrient concentrations among sites is due to site characteristics, with soil organic nature being a dominant factor. In contrast, most of the variation in drainage volume among years and studies appeared to be related to weather patterns. Thus, nutrient concentrations mostly vary in space (site-to-site), and drainage volumes mostly vary in time (season-to-season).

Average annual TN exports determined in the forested study sites reviewed in this report ranged from 2.3 to 23.9 kg/ha/yr (Table 5.11). However, annual TN exports were less than 7.5 kg/ha for all sites reported except those from the Parker Tract on organic soils. Export of TN from the Morrison Tract is also presumed to be high but not estimated due to incomplete seasonal data. Annual TN export values from forested stands in the Parker Tract on organic soils were in the range typically

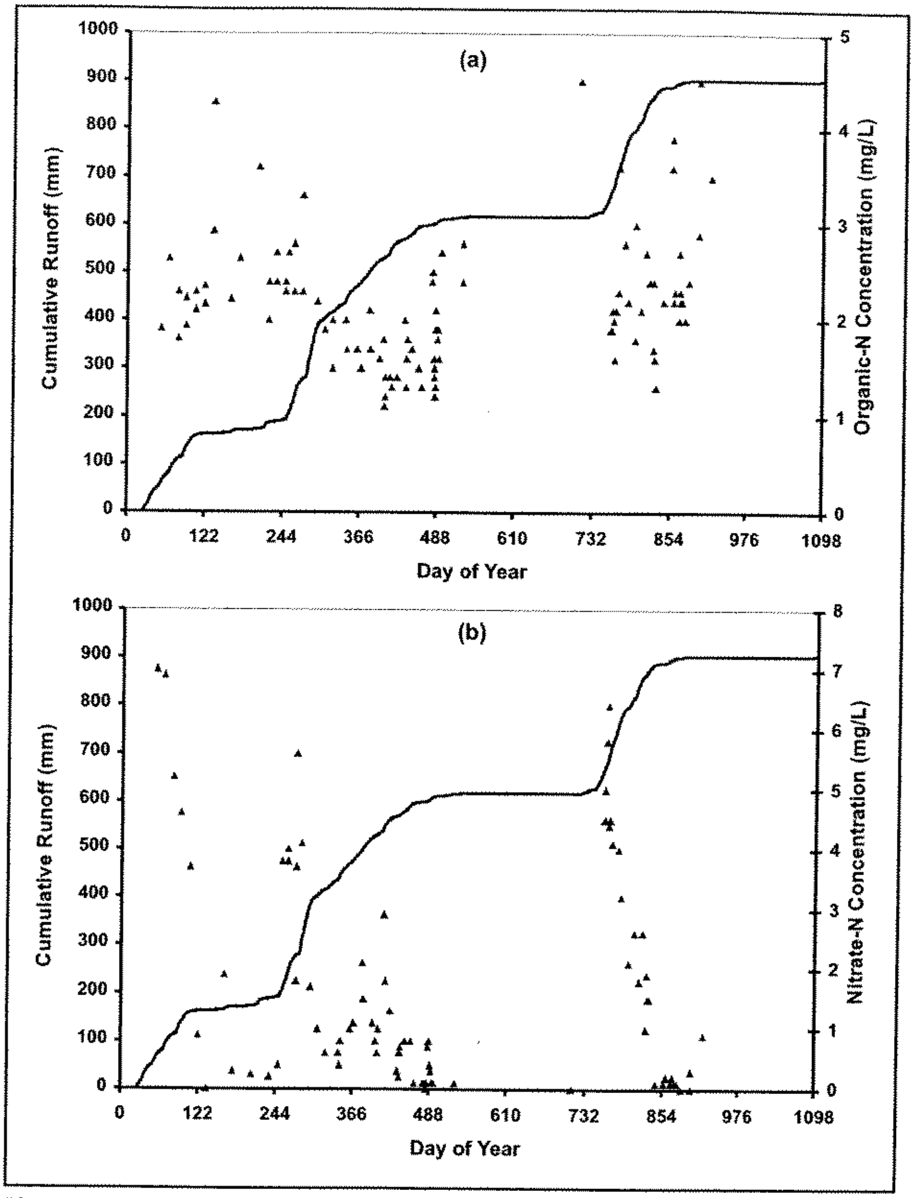


Figure 6.10. Cumulative runoff and concentrations of (a) Org-N and (b) NO_3-N measured at the Parker Tract S4 site for 1996 to 1998.

reported for agricultural croplands in eastern North Carolina with conventional drainage (Evans et al., 1995). In a summary of 125 site years of field data from agricultural studies in eastern North Carolina, Evans et al. reported average annual TN exports of 31.1 and 13.8 kg/ha, respectively, from agricultural lands with improved subsurface and surface drainage. Similarly, Chescheir et al. (1996) reported an average annual TN export of 20 kg/ha from a three-year experiment on agricultural sites with conventional subsurface drainage. The predicted range of TN exports reported for agricultural lands in eastern North Carolina is 8.6 to 44.4 kg/ha/yr based on a modeling study for cropland conditions representative of practices in the region (Chescheir et al., 1990). With the exception of the Parker Tract, all of the forested sites had reported exports below the predicted range for croplands.

Annual TP export from forested sites ranged from 0.05 to 0.36 kg/ha. These

TP export values are only slightly lower than TP export values reported from agricultural lands in the region (Evans et al., 1995). Generally, TP export from croplands in the coastal plain is low due to the flat topography and low sediment losses. Evans et al. reported average annual TP export rates of 0.21 and 0.48 kg/ha, respectively, from agricultural lands with improved subsurface and surface drainage. One notable bias in the database of site years from croplands is that most of the data was from mineral soils. It is likely that TP export from croplands on organic soils is higher than the range reported by Evans et al. For example, Chescheir et al. (1990) predicted the range of TP exports from conventionally drained agricultural lands was 0.07 kg/ha/yr for improved subsurface drainage on mineral soil to 0.86 kg/ha/yr for improved surface drainage on organic soil.

Seasonal hydrology was found to play an important role in nutrient export rates. In all of the studies reported, a large fraction of annual TN export occurred during the winter quarter concurrent with elevated outflow. The same was true for TP export, except for the Carteret D1 site and the Parker Tract F6 block, where TP export was highest in the fall. Another hydrologic factor affecting the seasonal distribution of nutrient exports was elevated nutrient exports in the summer or fall quarter in years with large tropical storms and the associated excessive rainfall. This was particularly true for TN and NO_3-N from the Parker Tract in 1996 when high outflow associated with three tropical storms flushed accumulated NO_3-N out of the soil profile during the fall rather than during the winter. Elevated losses of TP were also reported during the summer and fall seasons at some sites. Spring was usually the season with the lowest nutrient export.

LITERATURE CITED

Amatya, D. M., R. W. Skaggs, and J. D. Gregory. 1996. Effects of controlled drainage on the hydrology of a drained pine plantation in the North Carolina coastal plains. *J. Hydrol.* 181:211-232.

Amatya, D. M., R. W. Skaggs, J. D. Gregory, and R. B. Herrmann. 1997. Hydrology of a drained forested pocosin watershed. *J. Am. Water Resour. Assoc.* 33:535-546.

Amatya, D. M., J. W. Gilliam, R. W. Skaggs, M. E. Lebo, and R. G. Campbell. 1998. Effects of controlled drainage on forest water quality. *J. Environ. Qual.* 27:923-935.

Amatya, D. M., R. W. Skaggs, and J. D. Gregory. 1995. Comparison of methods for estimating REF-ET. *J. Irrig. Drain. Eng.* 121(6):427-435.

Amatya, D. M. 1993. "Hydrologic modeling of drained forested lands." Ph.D. dissertation, Department of Biological and Agricultural Engineering, North Carolina State University, Raleigh, N.C.

American Public Health Association. 1989. *Standard methods for the examination of water and wastewater,* 17th ed. APHA, Washington, D.C.

Chescheir, G. M., R. W. Skaggs, and J. W. Gilliam. 1990. Effects of water management and land use practices on hydrology and water quality in the Albemarle-Pamlico region. Rep. 90-09. Albemarle-Pamlico Estuarine Study. North Carolina Department of Environment, Health, and Natural Resources, Raleigh, N.C.

Chescheir, G. M., D. M. Amatya, and R. W. Skaggs. 1995. Monitoring the water balance of a natural forested wetland. *In* K. L Campbell (ed.) *Versatility of wetlands in the agricultural landscape.* American Society of Agricultural Engineers, St. Joseph, Mich. pp. 451-462.

Chescheir, G. M., R. W. Skaggs, J. W. Gilliam, M. A. Breve, C. L. Munster, R. O. Evans, R. B. Leidy, and J. E. Parsons. 1996. Effects of drainage and water table control on groundwater and surface water quality. Part II. Experimental results and simulation models. Water Resour. Res. Inst. of the Univ. of North Carolina, North Carolina State University, Rep. 301, Raleigh, N.C.

Chescheir, G. M., D. M. Amatya, G. P. Fernandez, R. W. Skaggs, and J. W. Gilliam. 1998. Monitoring and modeling the hydrology and water quality of a lower coastal plain watershed. In *Watershed management: moving from theory to implementation.* Water Environment Federation, Alexandria, Va. pp. 215-222.

Daniel, C., III. 1981. Hydrology, geology, and soils of pocosins: A comparison of natural and altered systems. *In* C. J. Richardson (ed.) *Pocosins: A conference on alternate uses of the coastal plain freshwater wetlands of North Carolina.* Hutchinson Ross Publishing Company, Stroudsburg, Pa. pp. 69-108.

Dodd, R. C., G. McMahon, and S. Stichter. 1992. Watershed planning in the Albemarle-Pamlico estuarine system: Annual average nutrient budgets. Rep. 92-10. Albemarle-Pamlico Estuarine Study. North Carolina Department of Environment, Health, and Natural Resources, Raleigh, N.C.

Eder, B. K., J. M. Davis, and P. J. Robinson. 1983. *Variations in monthly precipitation over North Carolina.* Water Resour. Res. Inst. of the Univ. of North Carolina, North Carolina State University, Rep. 185, Raleigh, N.C.

Evans, R. O., J. W. Gilliam, and R. W. Skaggs. 1995. Controlled versus conventional drainage effects on water quality. *J. Irrig. Drain. Eng.* 121(4):271-276.

Fromm, J. H., and R. B. Herrmann. 1996. *Jones 5 fertilizer runoff monitoring - 1992.* Technical Report, Southern Environmental Field Station, Weyerhaeuser Company, New Bern, N.C.

Heath, R. C. 1975. *Hydrology of the Albemarle-Pamlico region of North Carolina.* USGS Water Resource Investigations 9-75. U.S. Geological Survey, Raleigh, N.C.

Herrmann, R. B., and W. M. White. 1996. *Jones 5 fertilizer runoff monitoring - 1983.* Technical Report, Southern Environmental Field Station, Weyerhaeuser Company, New Bern, N.C.

Howarth, R. W., G. Billen, D. Swaney, A. Townsend, N. Jaworski, K. Lajtha, J. A. Downing, R. Elmgren, N. Caraco, T. Jordan, F. Berendse, J. Freney, V. Kudeyarov, P. Murdoch, and Zhu Zhao-Liang. 1996. Regional nitrogen budgets and riverine N and P fluxes for the drainages to the North Atlantic Ocean: natural and human influences. *Biogeochem.* 35: 75-139.

Kirby-Smith, W. W., and R. T. Barber, 1979. *The water quality ramifications in estuaries of converting forest to intensive agriculture.* Water Resour. Res. Inst. of the Univ. of North Carolina, North Carolina State University, Rep. 148, Raleigh, N.C.

Konyha, K. D., R. W. Skaggs, and J. W. Gilliam. 1992. Efects of drainage and water management practices on hydrology. *J. Irrig. Drain. Eng.* 118: 807-819.

Kronvang, B., R. Grant, S. E. Larsen, L. M. Svendsen, and H. E. Andersen. 1995. Non-point-source nutrient losses to the aquatic environment in Denmark: Impact of agriculture. *Mar. Freshwater Res.* 46: 167-177.

Lebo, M. E., and R. B. Herrmann. 1998. Harvest impacts on forest outflow in coastal North Carolina. *J. Environ. Qual.* 27:1382-1395.

McCarthy, E. J., R. W. Skaggs, and P. Farnum. 1991. Experimental determination of the hydrologic components of a drained forest watershed. *Trans. Am. Soc. Agric. Eng.* 34(5):2031-2039.

North Carolina Division of Environmental Management. 1993. *Neuse River basinwide water quality management plan.* Water Quality Section, N.C. DEM, Department of Environmental Health and Natural Resources, Raleigh, N.C.

North Carolina Division of Environmental Management. 1994. *Tar-Pamlico River basinwide water quality management plan.* Water Quality Section, N.C. DEM, Department of Environmental Health and Natural Resources, Raleigh, N.C.

North Carolina Division of Water Quality. 1998. *Neuse River basinwide water quality plan.* NCDWQ, N.C. Department of Environmental and Natural Resources, Raleigh, N.C.

North Carolina Division of Water Quality. 1999. *Tar-Pamlico River basinwide water quality plan.* NCDWQ, N.C. Department of Environmental and Natural Resources, Raleigh, N.C.

Preston, S. D., V. J. Bierman Jr., and S. E. Silliman. 1989. An evaluation of methods for the estimation of tributary mass loads. *Water Resour. Res.* 25(6):1379-1389.

Richards, R. P., and J. Holloway. 1987. Monte Carlo studies of sampling strategies for estimating tributary loads. *Water Resour. Res.* 23(10):1939-1948.

Robertson, D. M., and E. D. Roerish. 1999. Influence of various water quality sampling strategies on load estimates for small streams. *Water Resour. Res.* 35(12): 3747-3759.

Schreiber, J. D., P. D. Duffy, and D. C. McClurkin. 1976. Dissolved nutrient losses in storm runoff from five southern pine watersheds. *Environ. Qual.* 5:201-205.

Schueler, T. R. 1987. *Controlling urban runoff: A practical manual for planning and designing urban BMPs.* Metropolitan Washington Council of Governments, Washington, D.C.

Shepard, J. P. 1994. Effects of forest management on surface water quality in wetland forests. *Wetlands,* 14:18-26.

Skaggs, R. W., J. W. Gilliam, and R. O. Evans. 1991. A computer simulation study of pocosin hydrology. *Wetlands* 11:399-416.

Skaggs, R. W., J. W. Gilliam, T. J. Sheets, and J. S. Barnes. 1980. *Effect of agricultural land development on drainage waters in the North Carolina tidewater region.* Water Resour. Res. Inst. of the Univ. of North Carolina, North Carolina State University, Rep. 159, Raleigh, N.C.

Smith, K. L. 1994. "Assessing water quality impacts of forest management activities in pocosin wetlands in eastern North Carolina." M.S. thesis, Graduate School, Univ. of Georgia, Athens, Ga.

Turner, R. E., and N. N. Rabalais. 1991. Changes in Mississippi River water quality this century—Implications for coastal food webs. *Bioscience.* 41:140-147.

U.S. Environmental Protection Agency. 1992. *Managing nonpoint source pollution.* EPA-506/9-90. Office of Water, U.S. EPA, Washington, D.C.

U.S. Environmental Protection Agency. 1993. *Guidance specifying management measures for sources of nonpoint pollution in coastal waters.* EPA-840-B-92-002. Office of Water, U.S. EPA, Washington, D.C.

U.S. Environmental Protection Agency. 1994. *National water quality inventory: 1992 report to Congress.* EPA-841-R-94-001. Office of Wetlands, Oceans, and Watersheds. Washington, D.C.

Alphabetical List of Soil Series that Occurred on the Forested Sites

Arapahoe - Coarse-loamy, mixed, semiactive, nonacid, thermic Typic Humaquepts.

Argent - Fine, mixed, active, thermic Typic Endoaqualfs.

Bayboro - Fine, mixed, semiactive, thermic Umbric Paleaquults.

Belhaven - Loamy, mixed, dysic, thermic Terric Haplosaprists.

Bethera - Fine, mixed, semiactive, thermic Typic Paleaquults.

Brookman - Fine, mixed, superactive, thermic Umbric Endoaqualfs.

Cape Fear - Fine, mixed, semiactive, thermic Typic Umbraquults.

Croatan - Loamy, siliceous, dysic, thermic Terric Haplosaprists.

Dare - Dysic, thermic Typic Haplosaprists.

Deloss - Fine-loamy, mixed, semiactive, thermic Typic Umbraquults.

Grifton - Fine-loamy, siliceous, semiactive, thermic Typic Endoaqualfs.

Icaria - Fine-loamy over sandy or sandy-skeletal, siliceous, semiactive, thermic Typic Umbraquults.

Leaf - Fine, mixed, active, thermic Typic Albaquults.

Lynchburg - Fine-loamy, siliceous, semiactive, thermic Aeric Paleaquults.

Masontown - Coarse-loamy, siliceous, active, nonacid, thermic Cumulic Humaquepts.

Muckalee - Coarse-loamy, siliceous, nonacid, thermic Typic Fluvaquents.

Murville - Sandy, siliceous, thermic Umbric Endoaquods.

Pantego - Fine-loamy, siliceous, semiactive, thermic Umbric Paleaquults.

Pettigrew - Fine, mixed, semiactive, nonacid, thermic Histic Humaquepts.

Ponzer - Loamy, mixed, dysic, thermic Terric Haplosaprists.

Portsmouth - Fine-loamy over sandy or sandy-skeletal, mixed, semiactive, thermic Typic Umbraquults.

Pungo - Dysic, thermic Typic Haplosaprists.

Rains - Fine-loamy, siliceous, semiactive, thermic Typic Paleaquults.

Roanoke - Fine, mixed, semiactive, thermic Typic Endoaquults.

Stockade - Fine-loamy, mixed, superactive, thermic Umbric Endoaqualfs.

Tomotley - Fine-loamy, mixed, semiactive, thermic Typic Endoaquults.

Torhunta - Coarse-loamy, siliceous, active, acid, thermic Typic Humaquepts.

Wasda - Fine-loamy, mixed, semiactive, acid, thermic Histic Humaquepts.

Weeksville - Coarse-silty, mixed, semiactive, acid, thermic Typic Humaquepts.

Woodington - Coarse-loamy, siliceous, semiactive, thermic Typic Paleaquults.