This is not a peer-reviewed article.

Paper Number: 032037
An ASAE Meeting Presentation

Hydrology and Water Quality of Forested Lands in Eastern North Carolina

G. M. Chescheir[1], M. E. Lebo[2], D. M. Amatya[3], J. Hughes[2], J. W. Gilliam[4], R. W. Skaggs[1], and R. B. Herrmann[2]

1) Biological and Agricultural Engineering Dept, NC State University, Raleigh, NC 27695-7625
2) Weyerhaeuser Company, Southern Environmental Field Station, New Bern, NC 28563-1391
3) USDA Forest Service, Center for Forested Wetlands Research, Charleston, SC 29414
4) Department of Soil Science, NC State University, Raleigh, NC 27695-7619

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

Abstract. *More than 100 site years of hydrology and water quality data spanning 25 years (1976-2000) were compiled from research and monitoring studies on forest stands with natural vegetation and tracts managed for timber production. A total of 41 watersheds located on poorly drained to very poorly drained soils on flat divides between coastal streams were included ranging in area from 7.3 to 6070 ha. Hydrology 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. The median annual hydrologic response (outflow as a percentage of precipitation) among the sites was 31%, with an interquartile range of 26-35%. Nutrient concentrations in forest outflow were generally low for most study sites compared with typical values for other land uses. Mean seasonal concentrations of nutrient fractions in drainage from 75% of the study sites were <1.8 mg/L for total N (TN), <0.08 mg/L for total P (TP). Concentrations of Org-N, TN, and TP were all consistently higher in drainage from organic soils compared with mineral soils for both paired comparisons and the overall data base. TN exports from 75% of the study sites were less than 6.5 kg/ha/yr, predominantly as Org-N and TP exports from all forest sites was <0.36 kg/ha/yr.*

Keywords. Forest Hydrology, Water Quality, Nonpoint Sources, Nitrogen, Phosphorus

Introduction

The relative impact of land use on hydrology and nutrient exports has received considerable attention in recent years as a means to better characterize nonpoint source nutrient loading to aquatic systems (e.g. Howarth et al., 1996; Turner and Rabalais, 1991). 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). In comparative studies, nutrient exports from forest lands are typically much less than those from more intensive land uses (e.g. Dodd et al., 1992).

A wide range of forest conditions exist on the flat divides between coastal streams and rivers on the North Carolina coastal plain (Figure 1). Important site characteristics such as, soil type, drainage intensity, site vegetation, and site location relative to dominant geological features, potentially affect hydrology and nutrient exports. While differing site characteristics result in site-to-site variations, differing weather patterns drive temporal variability that can result in large seasonal and annual variations of outflow rates, nutrient concentrations, and nutrient exports across all sites. The effects of varying spatial and temporal conditions on nutrient exports from forests in the coastal plain setting of eastern North Carolina has not yet been summarized or well documented.

Past work in eastern North Carolina has shown that nutrient exports from managed pine plantations in some regions are 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. The effects of managed

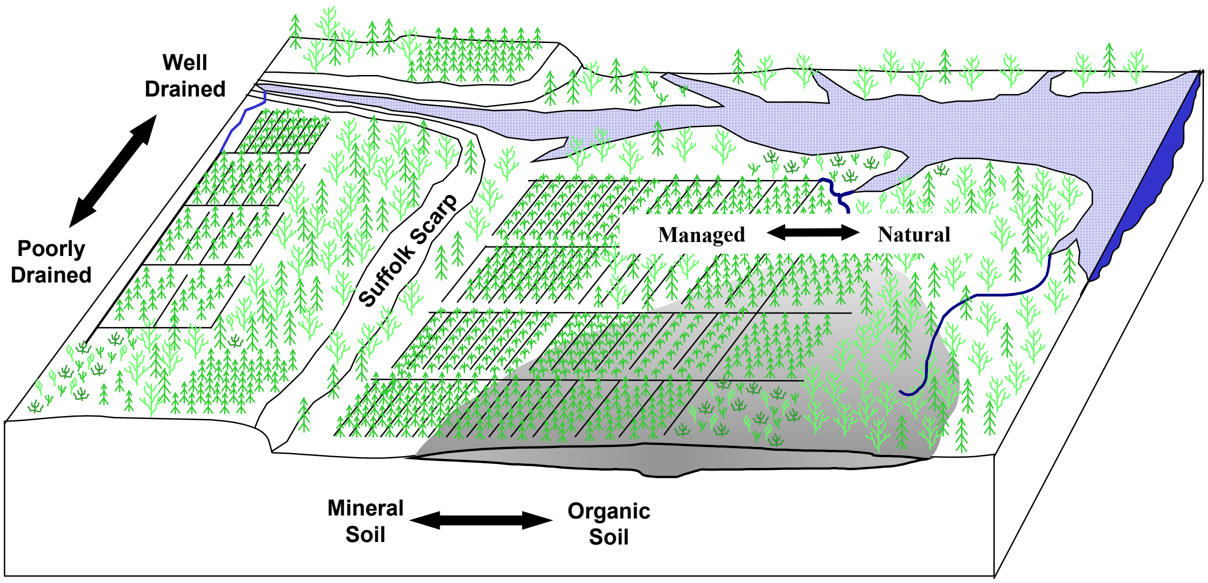


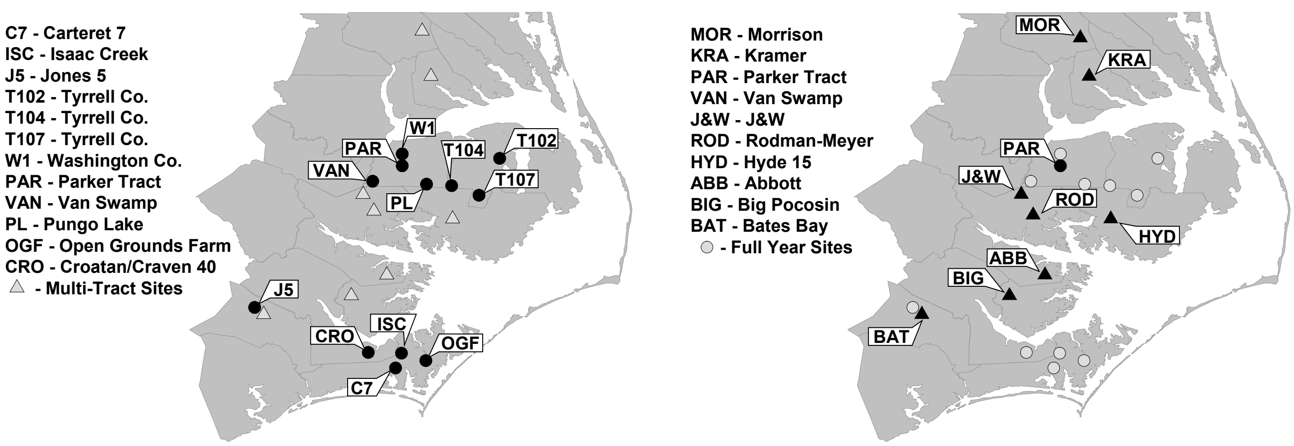
Figure 1. Conceptual drawing of the North Carolina coastal plain showing the range of conditions that occur in the landscape. The point shown here is that a forested site can exist anywhere along the gradients of soil organic content, drainage intensity, and forest vegetation.

forestry, an important commercial activity in North Carolina and throughout the southeast, on hydrology and nutrient exports in eastern North Carolina has also not been summarized or well documented for the variety of coastal plain settings.

The purpose of this project is to assess baseline forest outflow characteristics for the variety of conditions that exist on the flat divides between coastal streams and rivers in the coastal plain of eastern North Carolina.

Site Descriptions

More than 100 site years of hydrology and water quality data spanning 25 years (1976-2000) 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 6070 ha; 16 had natural forest vegetation, and 25 were intensively managed loblolly pine plantations (Table 1). 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. Thirty watersheds were included in 9 full-year studies (Figure 2a) and eleven watersheds were included in 1 multi-tract survey of nutrient concentrations in outflow during the winter and spring (Figure 2b). The studies ranged in intensity from monthly water sampling without flow measurement to continuous flow measurement with automatic flow proportioned water sampling (Table 2). More detailed descriptions of the various site can be found in (Chescheir et al., 2003).



A B

Figure 2. Map of eastern North Carolina showing the locations of the (A) full-year sites and the (B) Multi-tract sites.

Table 1. Characteristics for research study sites included in the review.

Site	*Block*	*Area (ha)*	*Soil Series*	*Drainage System (m)*			*Vegetation*
				Field	*Spacing*	*Depth*	
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	7.3	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	7.3	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 1. Characteristics for research study sites included in the review (*continued*)

Site	Block	Area (ha)	Soil Series	Drainage System (m) Field	Spacing	Depth	Vegetation
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. Study sampling designs for research study sites included in the review.

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).

Hydrology

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% (Figure 3), which is consistent with the 40-year mean annual ratio of excess water (rainfall – potential ET) to rainfall from regional weather stations (29-30%). Collectively, study sites in eastern North Carolina showed a consistent seasonal peak in outflow and hydrologic response in the winter (Figures 3 & 4); outflow was greater than 75 mm for all site years and exceeded 206 mm for half of the 84 winter (i.e. January-March) seasons studied (Figure 5a). 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 (Figure 5b). 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 (Figure 5c). 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 (Figure 5d). By the end of the fall, soil water conditions were usually wet again due to decreased ET in cooler months. More detailed hydrology of the various sites can be found in (Chescheir et al., 2003).

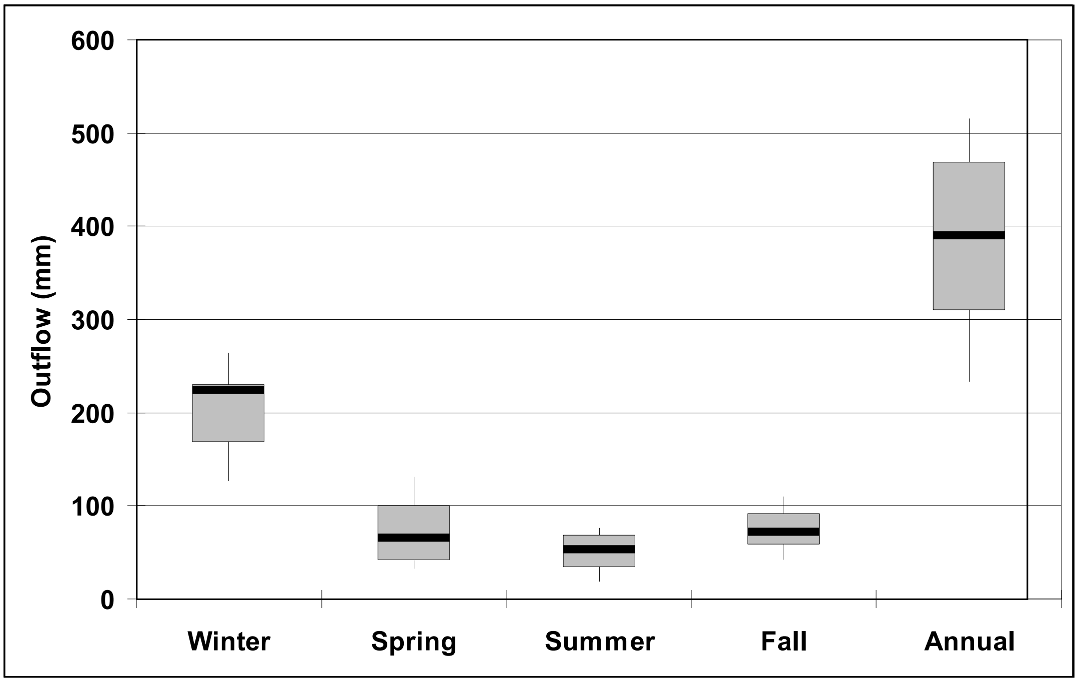


Figure 3. Distribution of mean seasonal and annual outflow for all sites. The box and wisker plots show values for 10th, 25th, 50th, 75th, and 90th percentile rankings.

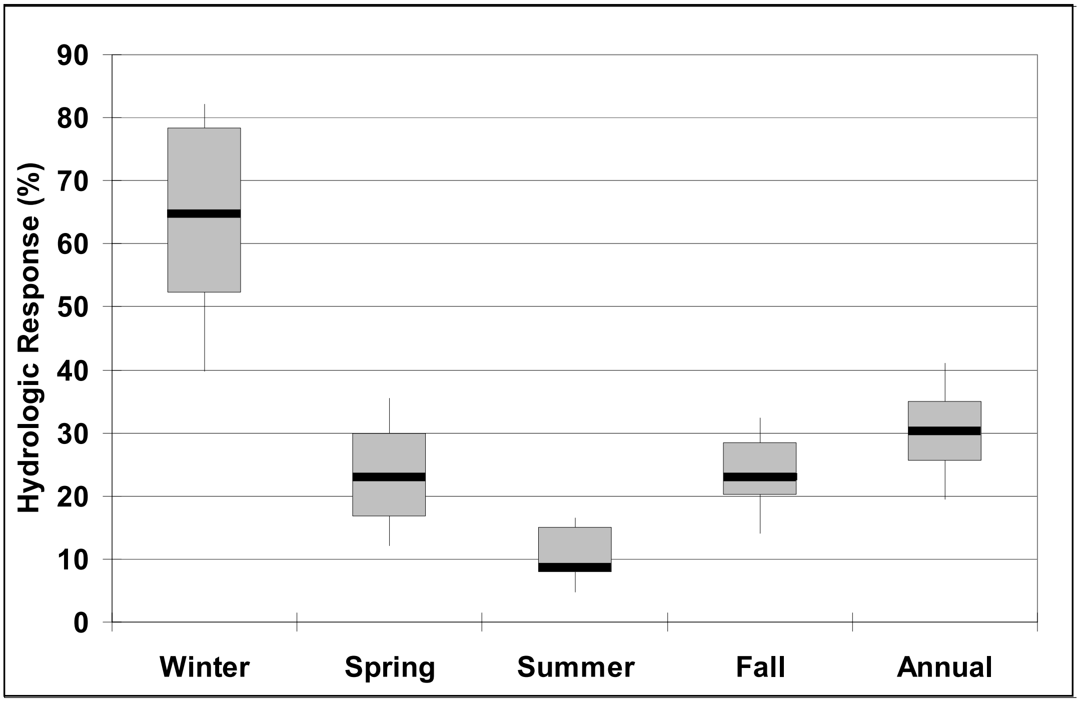


Figure 4. Distribution of mean seasonal and annual hydrologic response for all sites. The box and wisker plots show values for 10th, 25th, 50th, 75th, and 90th percentile rankings.

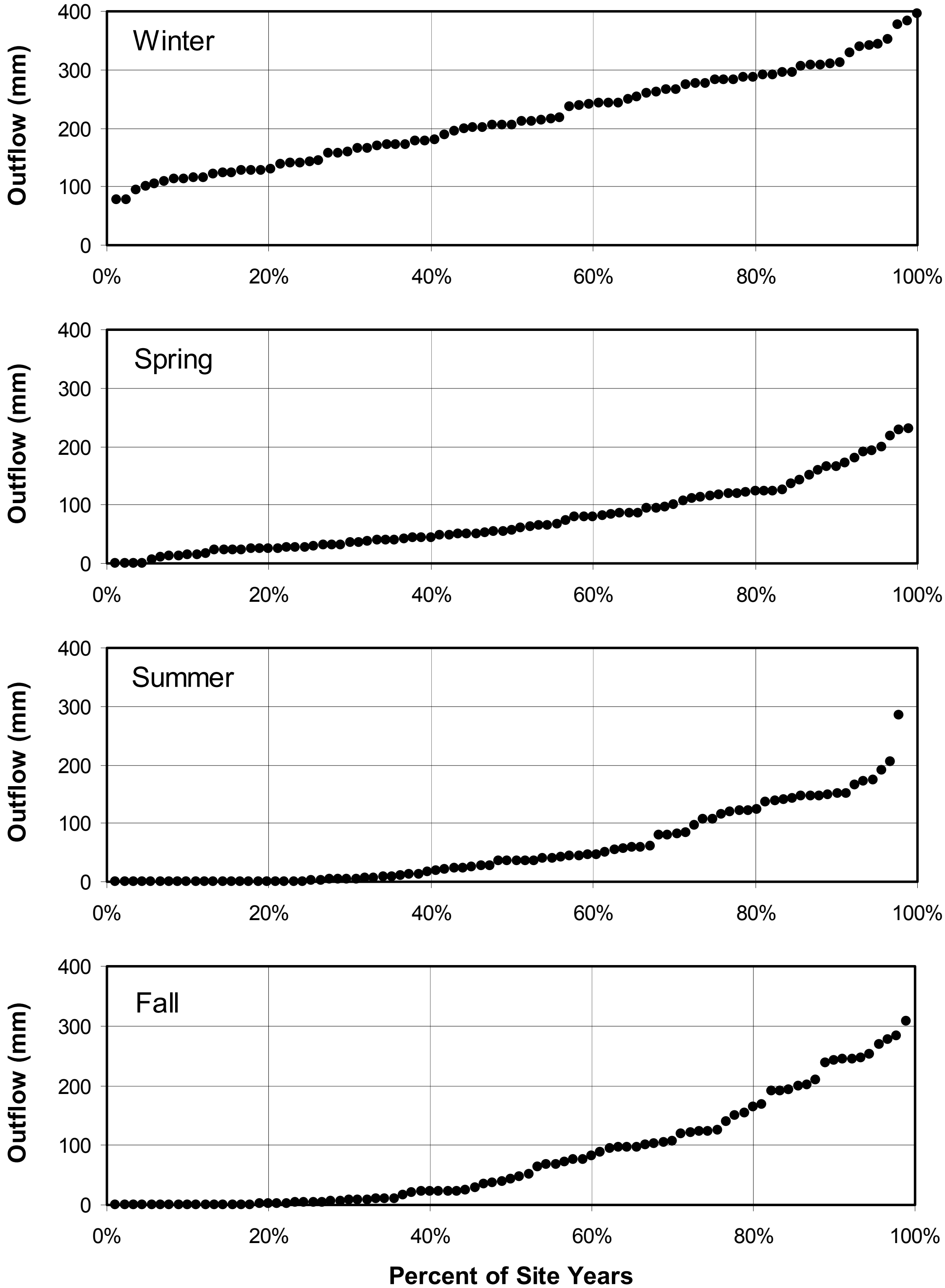

Winter
Spring
Summer
Fall
Outflow (mm)
0
100
200
300
400
0%
20%
40%
60%
80%
100%
Percent of Site Years

Figure 5. 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

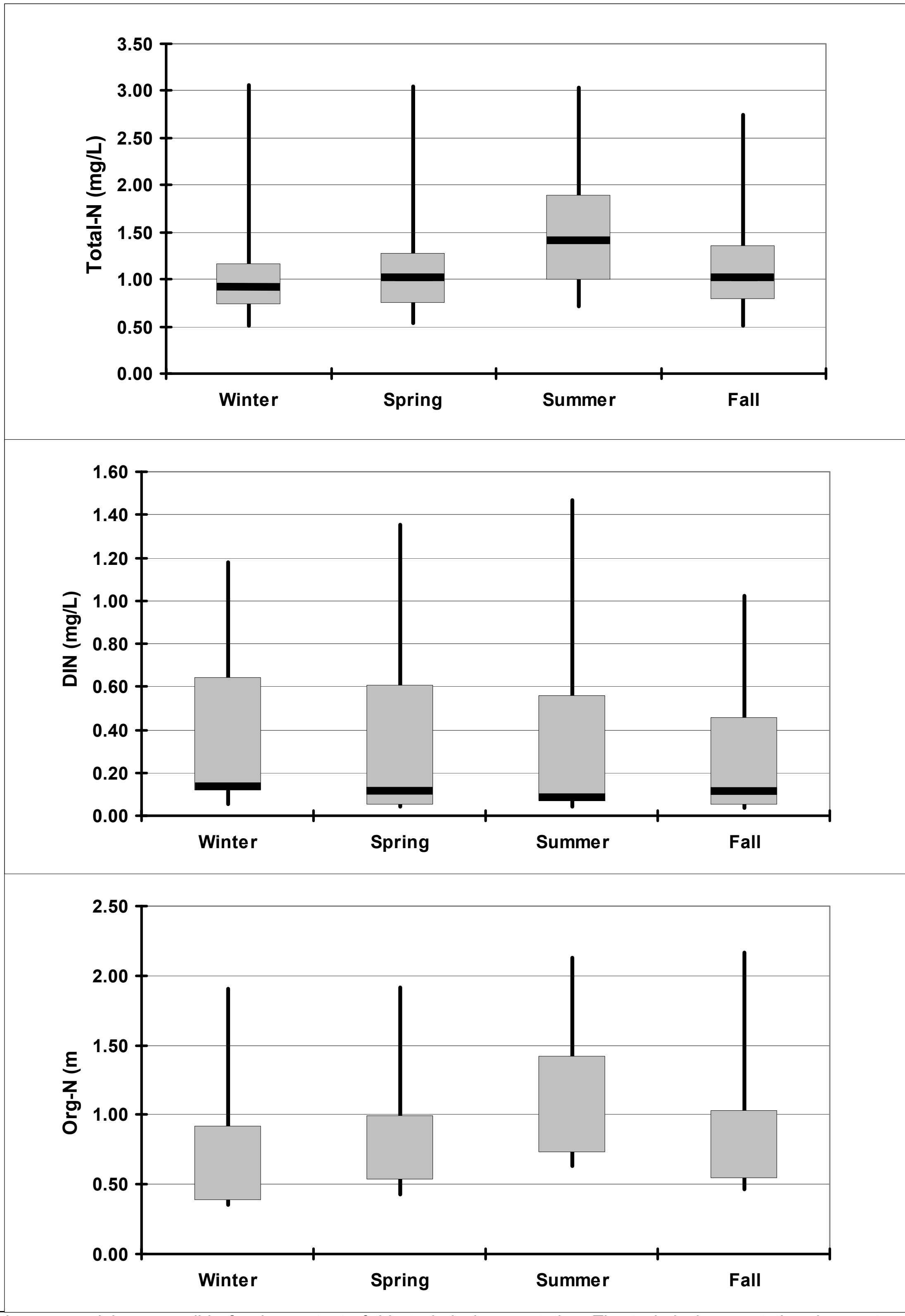
Nutrient Concentrations

Nutrient concentrations in forest outflow were generally low for most study sites compared with typical values for other land uses. Mean seasonal concentrations of nutrient fractions in drainage from 50% of the study sites were 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 (Figures 6 & 7). 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 0.60-0.76 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 (0.94-1.09 mg/L). For TP, the median concentration was also highest in the summer (0.064 mg/L) compared with other seasons (0.033-0.047 mg/L), but there was no consistent pattern across sites. More detailed descriptions of nutrient concentrations observed at the various sites can be found in (Chescheir et al., 2003).

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. Annual TN exports from 75% of the study sites were less than 6.5 kg/ha (Figure 8). 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 a majority (18 of 21) of the monitoring locations. For the three sites where Org-N was not the predominant form of N, annual DIN export accounted for 54-82% 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 (Figure 9).

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 (Figure 8). The same was true for TP export, with the exceptions of two sites where TP export was highest during the fall quarter (Figure 9). 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), 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.   More detailed descriptions of nutrient exports observed at the various sites can be found in (Chescheir et al., 2003).



3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Total-N (mg/L)
Winter
Spring
Summer
Fall
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
DIN (mg/L)
Winter
Spring
Summer
Fall
2.50
2.00
1.50
1.00
0.50
0.00
Org-N (m
Winter
Spring
Summer
Fall

Figure 6. 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 10^{th}, 25^{th}, 50^{th}, 75^{th}, and 90^{th} percentile rankings.

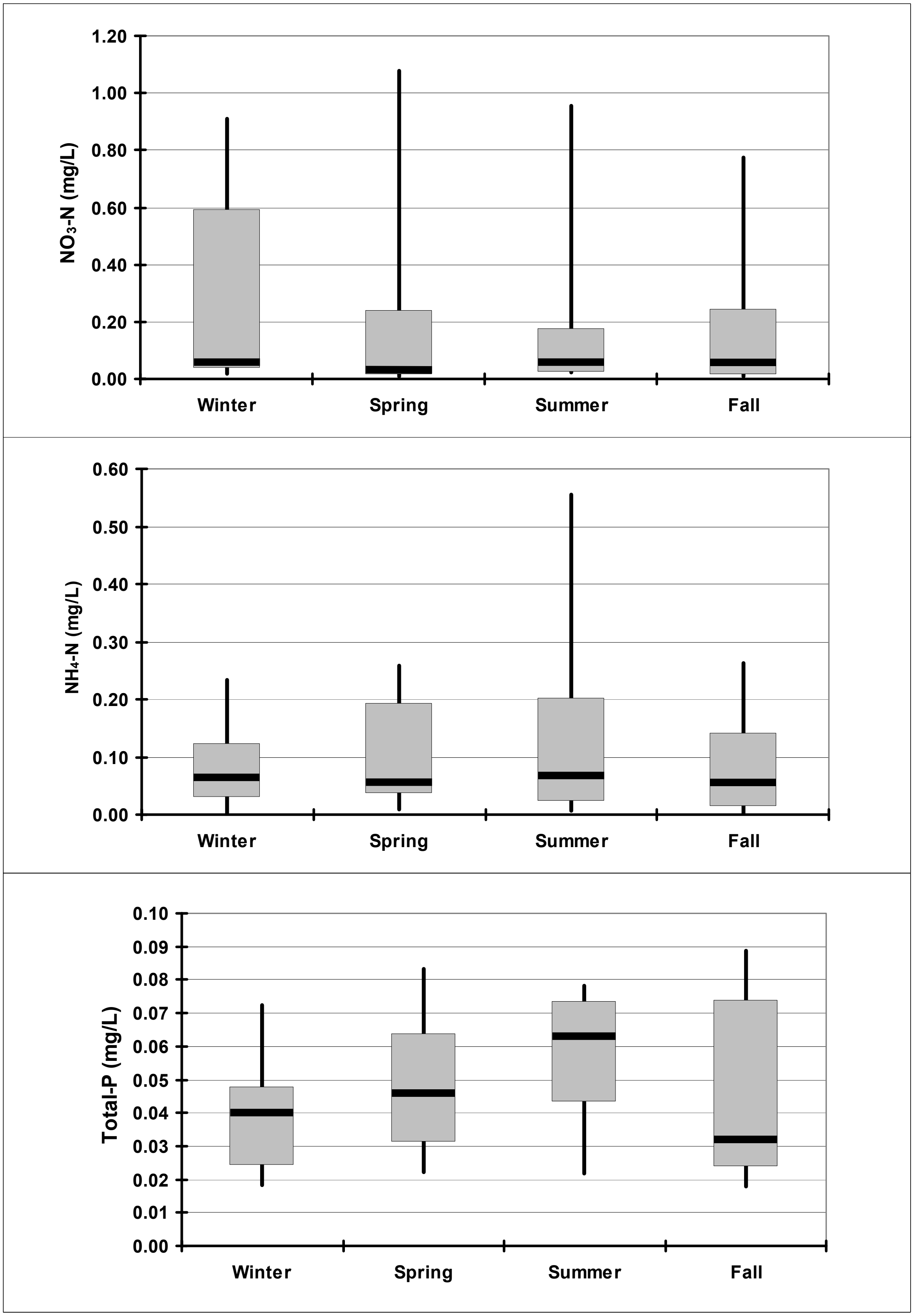

1.20
1.00
0.80
0.60
0.40
0.20
0.00
NO_3-N (mg/L)
Winter
Spring
Summer
Fall
0.60
0.50
0.40
0.30
0.20
0.10
0.00
NH_4-N (mg/L)
Winter
Spring
Summer
Fall
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Total-P (mg/L)
Winter
Spring
Summer
Fall

Figure 7. 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.

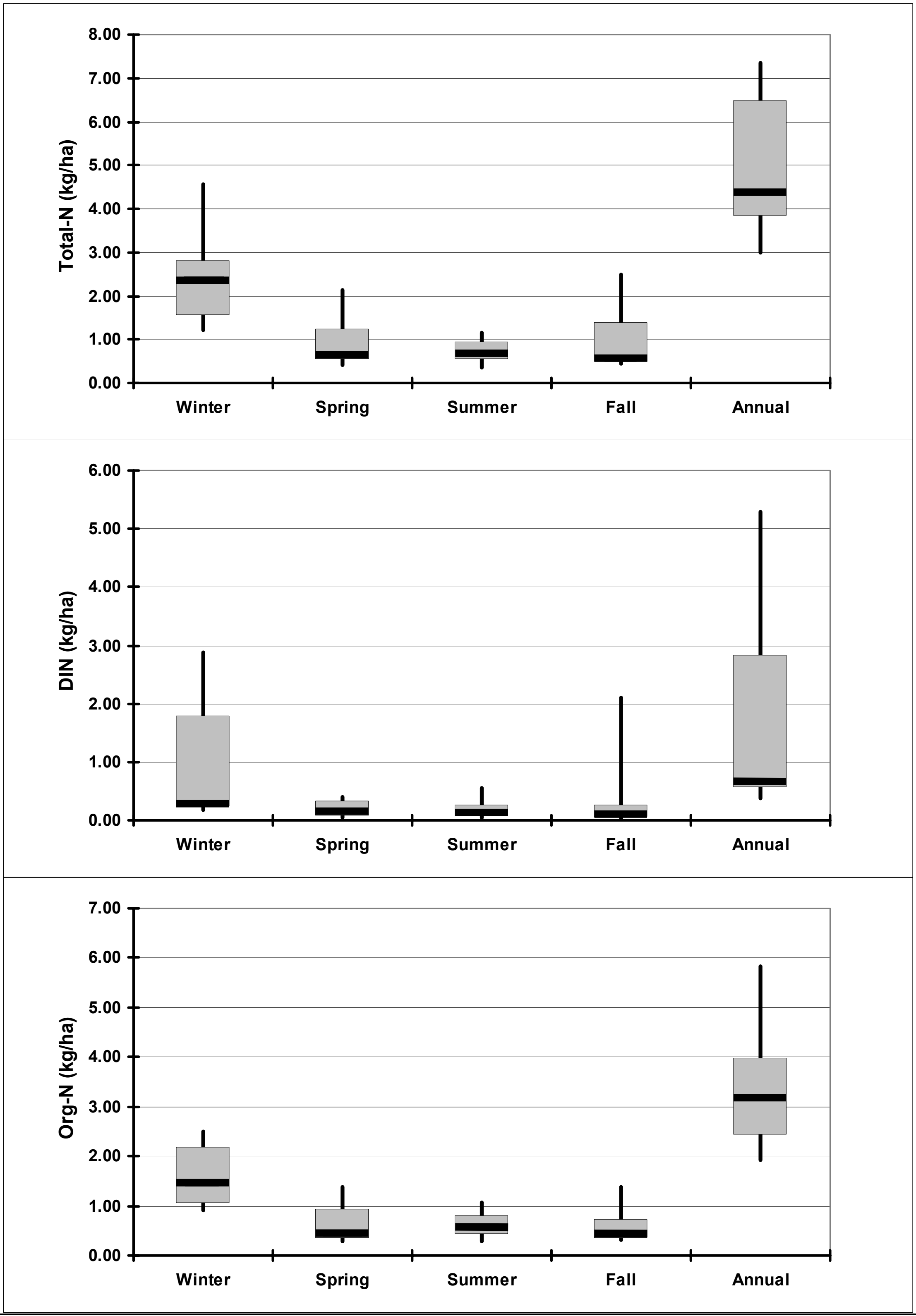

Total-N (kg/ha)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Winter
Spring
Summer
Fall
Annual
DIN (kg/ha)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Winter
Spring
Summer
Fall
Annual
Org-N (kg/ha)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Winter
Spring
Summer
Fall
Annual

Figure 8. Distribution of mean seasonal exports for TN, DIN, and Org-N. The box and wisker plots show values for 10th, 25th, 50th, 75th, and 90th percentile rankings.

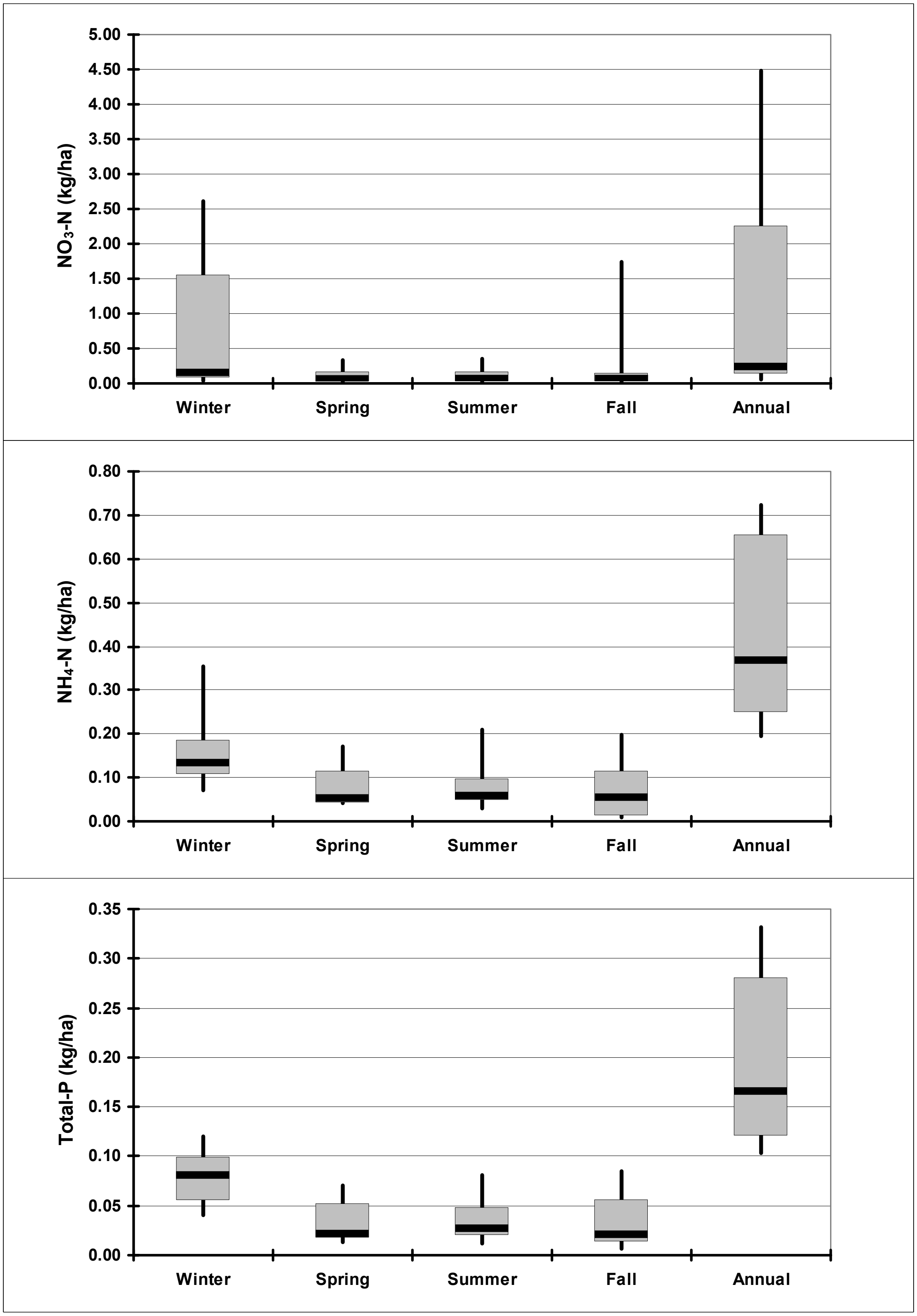

NO3-N (kg/ha)
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Winter
Spring
Summer
Fall
Annual
NH4-N (kg/ha)
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Winter
Spring
Summer
Fall
Annual
Total-P (kg/ha)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Winter
Spring
Summer
Fall
Annual

Figure 9. Distribution of mean seasonal exports for NO3-N, NH4-N, and Total-P. The box and wisker plots show values for 10^{th}, 25^{th}, 50^{th}, 75^{th}, and 90^{th} percentile rankings.

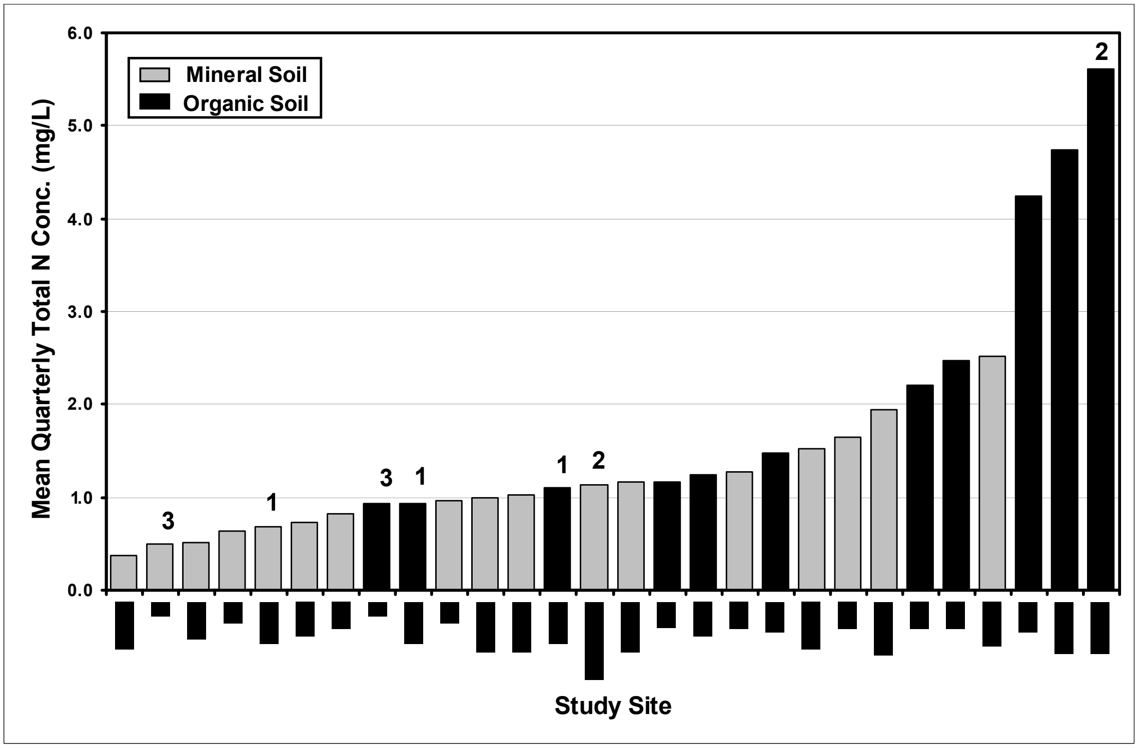
Effects of Site Characteristics

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 are 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 for both paired comparisons and the overall database (Figure 10). The impact of organic soils on the DIN concentrations was more variable. Four of the six highest DIN concentrations observed were from the sites on organic soils, but four of the seven lowest DIN concentrations were also from the sites on organic soils (Figure 11). 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 observed at 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 the 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 are available for more sites, were plotted geographically to evaluate whether concentrations were related to location (Figure 12). No consistent gradients in nutrient concentrations were identified. For the Neuse River basin, five of seven locations had TN concentrations 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 and Morrison tracts, 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 observed 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, 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 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 quarter rather than during winter outflow. Elevated losses of TP were also reported during the summer and


Mineral Soil
Organic Soil
Mean Quarterly Total N Conc. (mg/L)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
3
1
3
1
1
2
2
Study Site

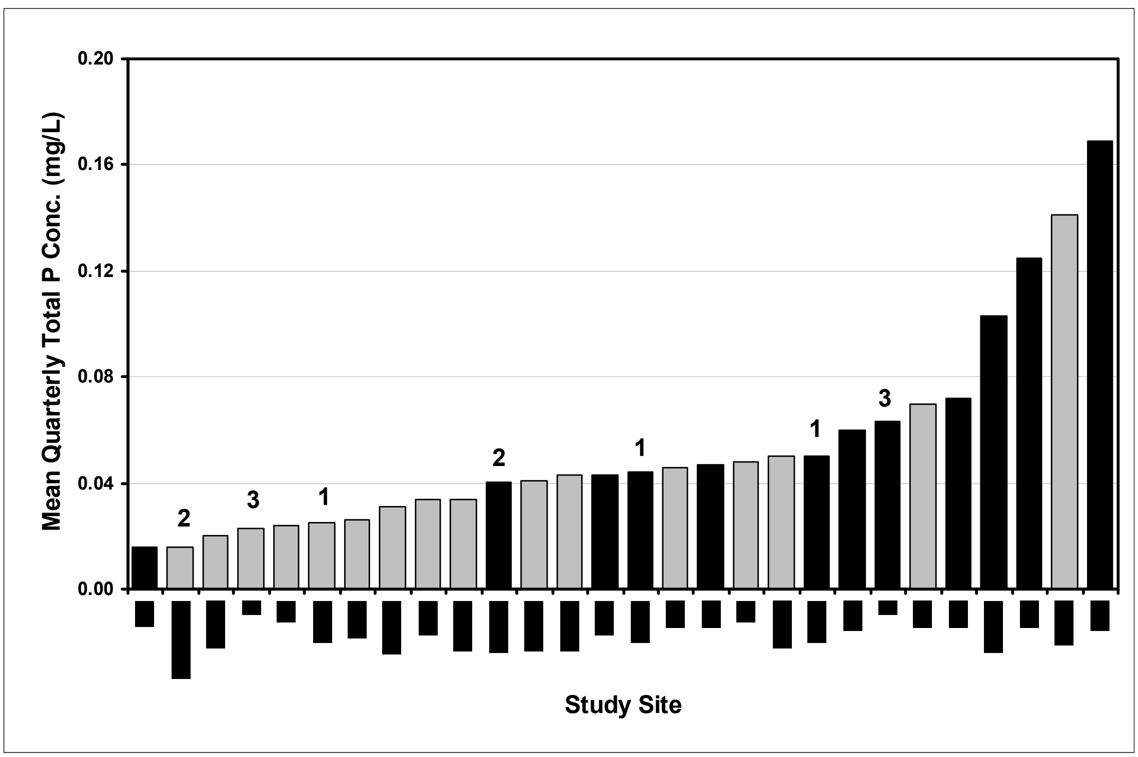
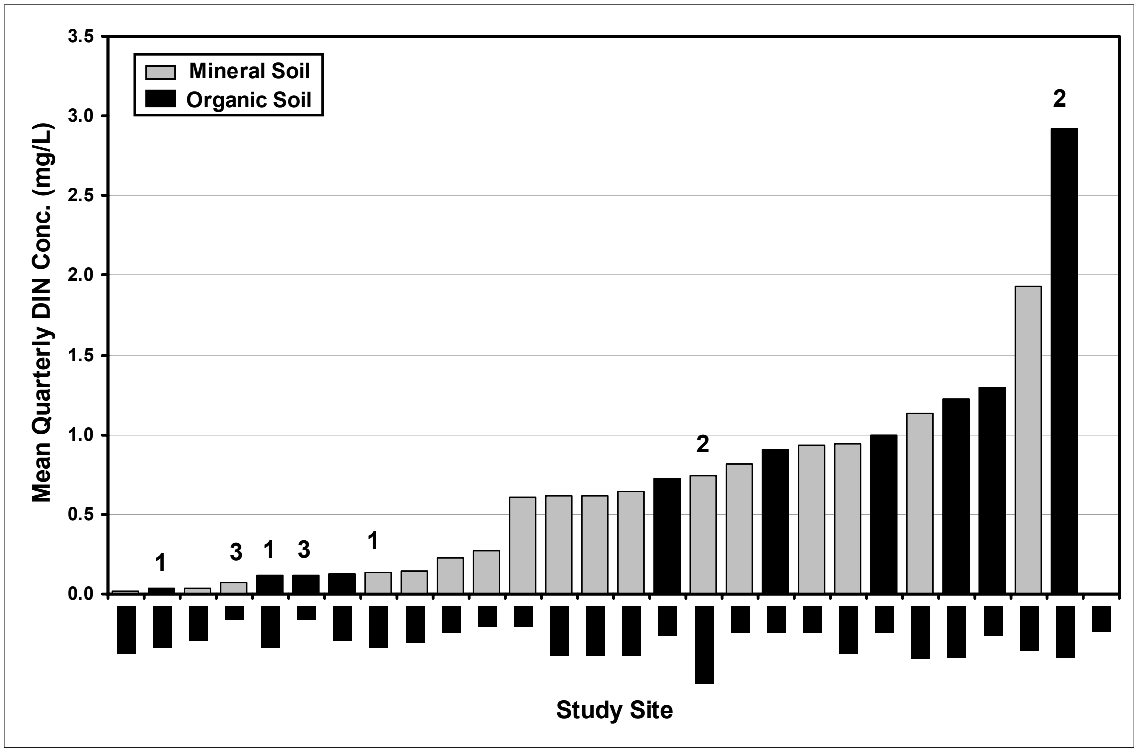

Mean Quarterly Total P Conc. (mg/L)
0.20
0.16
0.12
0.08
0.04
0.00
2
3
1
2
1
1
3
Study Site

Figure 10. 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.


Mineral Soil
Organic Soil
Mean Quarterly DIN Conc. (mg/L)
Study Site
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1
3
1
3
1
2
2

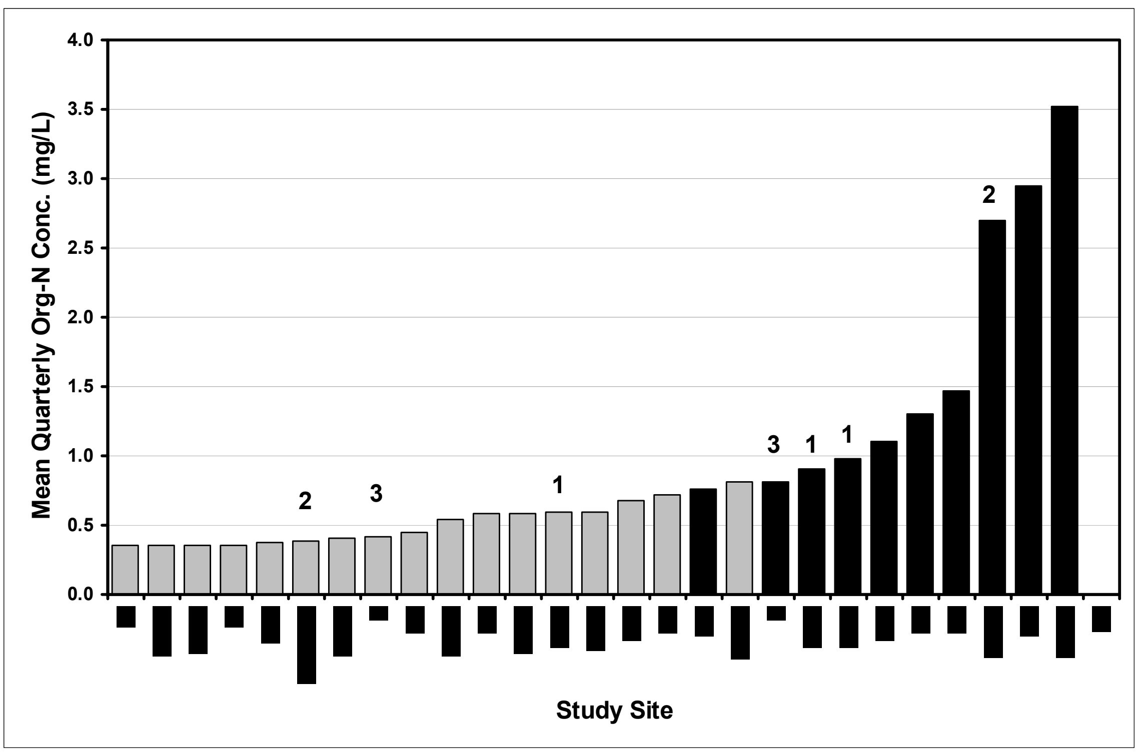

Mean Quarterly Org-N Conc. (mg/L)
Study Site
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
2
3
1
3
1
1
2

Figure 11. 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.

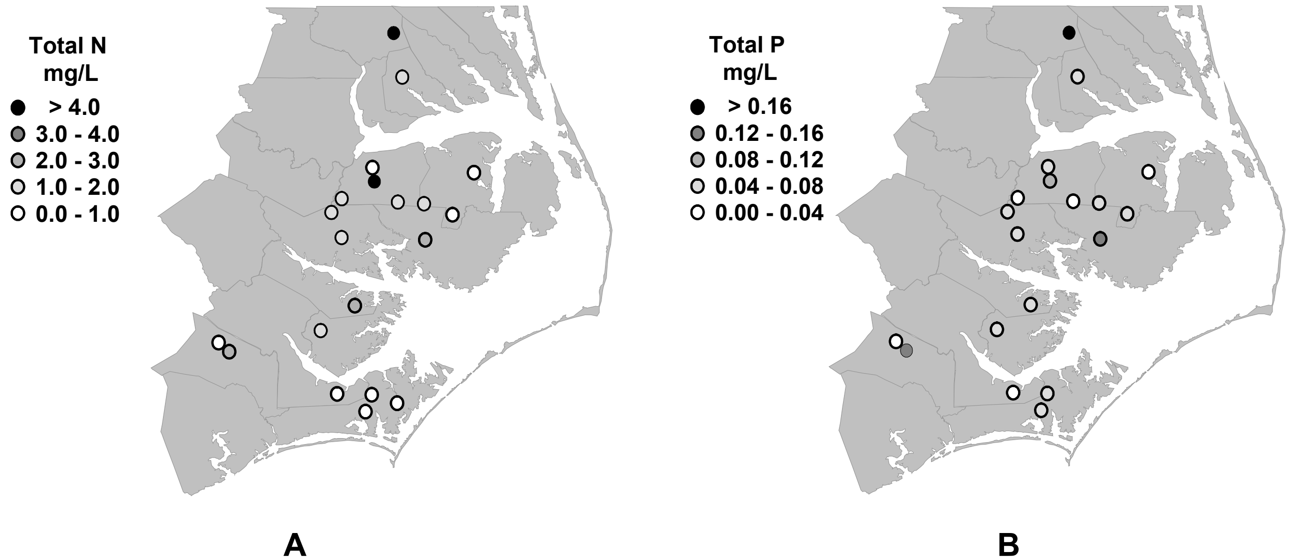


Figure 12. Distribution of study sites showing the mean winter quarter concentration for (A) TN and (B) TP in outflow from each site.

fall seasons at some sites. The spring season was usually the season with the lowest nutrient export. Because of the dependence of seasonal nutrient exports on hydrology, results from short-term studies conducted over 2-3 years need to be interpreted in the context of the seasonal rainfall distribution during the given years of study, particularly years affected by large, infrequent storms (e.g. hurricanes).

Conclusions

The purpose of this project is to assess baseline forest outflow characteristics for the variety of conditions that exist on the flat divides between coastal streams and rivers in the coastal plain of eastern North Carolina. More than 100 site years of hydrology and water quality data spanning 25 years (1976-2000) have been compiled from research and monitoring studies both on stands with natural vegetation and on tracts managed for timber production. The key summary points from this project are listed below:

- The median annual hydrologic response (outflow as a percentage of precipitation) among the sites was 31%, with an interquartile range of 26-35%.

- Seasonal variation in outflow was high. Outflow and hydrologic response at the sites were consistently higher in the winter quarter (January-March); outflow was >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. Mean seasonal concentrations of nutrient fractions in drainage from 50% of the study sites were <1.5 mg/L for total N (TN), <1.1 mg/L for organic N (Org-N), <0.1 mg/L for nitrate+nitrite N (NO_3-N), <0.1 mg/L for ammonium N (NH_4-N), and <0.07 mg/L for total P (TP).

- TN exports from 75% of the study sites were less than 6.5 kg/ha/yr, predominantly as Org-N at 18 of 21 sites. Annual TP export from all forest sites was <0.36 kg/ha. Maximum exports generally occurred during the winter months.

- Concentrations of Org-N, TN, and TP were all consistently higher in drainage from organic soils compared with mineral soils for both paired comparisons and the overall data base. Dissolved inorganic N (DIN) concentrations in drainage from organic soils were more variable than from mineral soils.

- The strong dependence of forest outflow nutrient concentrations on soil type confounds the evaluation of other factors since a large fraction of available data are from watersheds with artificial drainage on organic soils.

Acknowledgments

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 US 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).

References

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.

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, MI. pp. 451-462.

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.

Chescheir, G.M., M.E. Lebo, D.M. Amatya, J. Hughes, J.W. Gilliam, R.W. Skaggs, and R.B. Herrmann. 2003. Hydrology and water quality of forested lands in eastern North Carolina. Research Bulletin No. 320, N.C. Agricultural Research Service, N. C. State University, Raleigh, NC. 77 p.

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, NC.

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, NC.

Herrmann, R.B. and W.M. White. 1996. Jones 5 Fertilizer Runoff Monitoring - 1983. Technical Report, Southern Environmental Field Station, Weyerhaeuser Company, New Bern, NC.

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 & 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, NC.

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.

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, P. Farnum. 1991. Experimental determination of the hydrologic components of a drained forest watershed. Trans. Am. Soc. Agric. Eng. 34(5):2031-2039.

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, NC.

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.