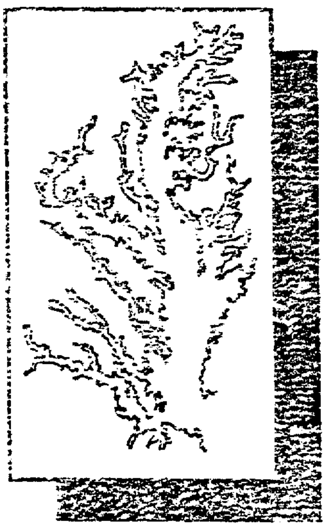
Task 18 FY 90
Final Work Product

Eroding Bank Nutrient Verification Study for the Lower Chesapeake Bay



by Nancy A. Ibison, Joseph C. Baumer, Carlton Lee Hill, Ned H. Burger and Jack E. Frye

held by

February 1992

Department of Conservation and Recreation
Division of Soil and Water Conservation
Shoreline Programs Bureau
Gloucester Point, VA

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EXECUTIVE SUMMARY

The 1990 report "Sediment and Nutrient Contributions of Selected Eroding Banks of the Chesapeake Bay Estuarine System" represented the first attempt to estimate the quantity of nitrogen and phosphorus contributed to the lower Chesapeake Bay by shoreline erosion. The sediment and nutrient contributions from 14 eroding banks on the mainstem of the Bay and tributary rivers were examined. Mean nitrogen and phosphorus loading concentrations and loading rates were calculated. The initial study provided insight into the magnitude of nutrient inputs from shoreline erosion.

The present study was undertaken to verify and expand the initial research. An additional 44 eroding banks along the lower Chesapeake Bay estuarine system were studied. A question regarding a possible error in the phosphorus measurements due to apatite contained in fossiliferous soil horizons was studied. The study also examined the impact of landuse on nutrient loading concentrations.

The findings of this study confirm the high variability in nutrient loading concentrations and loading rates determined in the initial study. The nutrient loading rates for shoreline erosion were much higher than similar rates used in agricultural nutrient loading calculations. The difference is due to the large volumes of soil lost from shoreline erosion.

The mean total phosphorus loading concentration for banks with fossils was approximately double the mean for banks without fossils. Mean inorganic phosphorus loading concentrations were the same for both groups.

Landuse was found to impact the nutrient loading concentrations. Four landuse categories were examined: active farms, fallow farms, wooded and rural residential. Active farms had the greatest mean total nitrogen and total phosphorus loading concentrations. The total nitrogen loading concentration for soils sampled from wooded land was equal to that of active farms. Rural residential land had the lowest mean nutrient loading concentrations.

The data from the study can be used with recent shoreline stabilization data to calculate nutrient reduction "credits" for the period from 1985 to 1990.

ACKNOWLEDGEMENTS

The authors wish to thank the following individuals for their contributions to this project. Thanks to C. Scott Hardaway and George Thomas of the College of William and Mary, Virginia Institute of Marine Science (VIMS) for project design and field work. Thanks to the staff of the VIMS sediment and nutrient analysis lab. Special thanks and credit to Susan Townsend of the Department of Conservation and Recreation, Division of Soil and Water Conservation for her perseverance with layout and printing of the report.

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I. INTRODUCTION

In the 1987 Chesapeake Bay Agreement, the participants targeted nitrogen and phosphorus contributions to the mainstem of the Chesapeake Bay for a 40% reduction by the year 2000. To meet this goal, all possible point and nonpoint source nutrient inputs need to be examined to determine where reductions are feasible. In previous assessments of nonpoint source nutrient inputs published by the U.S. Environmental Protection Agency, the contribution from shoreline erosion was not known (U.S. Environmental Protection Agency, 1982; U.S. Environmental Protection Agency, 1987, cited by Virginia Department of Conservation and Recreation, 1989).

In an effort to determine the magnitude of nutrient contributions from shoreline erosion, the study entitled "Sediment and Nutrient Contributions of Selected Eroding Banks of the Chesapeake Bay Estuarine System" was undertaken (Ibison et. al., 1990). The study represented the first attempt to estimate the quantity of nitrogen and phosphorus contributed to the lower Chesapeake Bay by shoreline erosion. In the report, the sediment and nutrient contributions from 14 sites on the mainstem of the Bay and tributary rivers were examined. The total contribution of nitrogen and phosphorus from shoreline erosion for the lower Chesapeake Bay was estimated using the mean nitrogen and phosphorus loading concentrations for the sites and the annual net soil loss from approximately 1,600 miles of tidal shoreline reported in Byrne and Anderson (1977).

The present study was undertaken to verify and expand the findings of the previous study. An additional 44 eroding banks along the Chesapeake Bay and tributary rivers were sampled. The sites represent different soil stratigraphies and landuse types. Landuse is known to influence nonpoint source pollution (U.S. Environmental Protection Agency, 1983).

The previous study also raised questions about the phosphorous analysis methods. Some of the banks studied have fossiliferous layers containing phosphorus in the form of the mineral apatite. Apatite phosphorus is unavailable for biological uptake and thought to only become available after extremely long periods of time (Johnson, personal communication). The phosphorus analysis methods use acid extractions to measure inorganic and total phosphorus. Questions were posed as to whether or not the methods would extract apatite phosphorus, and if so, how much apatite is present in the fossiliferous horizons. The staff at the nutrient lab of the Virginia Institute of Marine Science (VIMS) used different acid extraction methods and acid concentrations to try to isolate the more readily available phosphorus from apatite. Unfortunately, no method was found that would differentiate more readily available phosphorus from apatite phosphorous.

The present study was undertaken with the following objectives:

(1) To verify and expand the previous research on the nutrient and sediment contributions from eroding shoreline banks.

(2) To determine the effects of landuse on nutrient concentrations in eroding shoreline banks.

(3) To determine the difference in phosphorus concentrations between banks with and without fossiliferous layers.

Since the completion of the initial eroding bank nutrient study, VIMS has conducted the Virginia Bank Erosion Study (Hardaway et. al., in press) to determine the total length of shoreline erosion control structures installed between 1985 and 1990. The VIMS study documents how much land has been stabilized against erosion, resulting in a reduction in the nutrient loading from shoreline erosion. Using the expanded baseline nutrient loading data from this report and the VIMS shoreline stabilization data, it will be possible to estimate a reduction "credit" for the shoreline stabilization activities undertaken since the 1985 "base level" year.

II. SITE DESCRIPTION AND SAMPLING PROCEDURES

Site Selection

Forty-four sites were selected for the project using sites from the Virginia Bank Erosion Study (Hardaway et. al., in press). Initial selection was conducted by researchers at the Virginia Institute of Marine Science using the VIMS Shoreline Video Survey of 1990. Sites were field checked and sampled if suitable. Site locations are depicted in Figure 1. (GIS coordinates for the sites are reported in Appendix B.) The site name, county, reach, reach length, erosion rate, volume eroded, landuse, sampling date for nutrient samples and bank height above mean high water (MHW) are listed in Table 1. The reach, reach length, erosion rate and volume eroded information were obtained from Byrne and Anderson (1977). Since erosion rates were unavailable for 7 sites, the average Bay-wide erosion rate of 0.7 foot per year from Byrne and Anderson (1977) was used. Because all banks sampled were actively eroding, a rate of 0.7 foot per year represents a conservative, reasonable estimate.

Sampling Procedures

Field sampling involved collection of soil samples from the various distinct horizons on the bank face. Samples were taken directly from the bank face where undisturbed sediments were present. It was necessary to dig down to undisturbed soils where sloughing had occurred. The lithologic characteristics of the horizons, presence of fossil material and evidence of groundwater were noted. The sample positions and approximate horizon widths were measured with a stadia rod and hand level. The landuse at each site was also noted. Four basic landuse types were designated: active farmland, referring to cultivated cropland; fallow farmland, referring to presently uncultivated farmland; wooded land and rural residential land.

Two samples were taken from each horizon for nutrient and grain size analyses. The samples were placed in sterile whirlpaks and kept on ice while being transported back to the lab. The samples were frozen and stored for analysis. (The sediment and nutrient data are reported in Appendix A.)

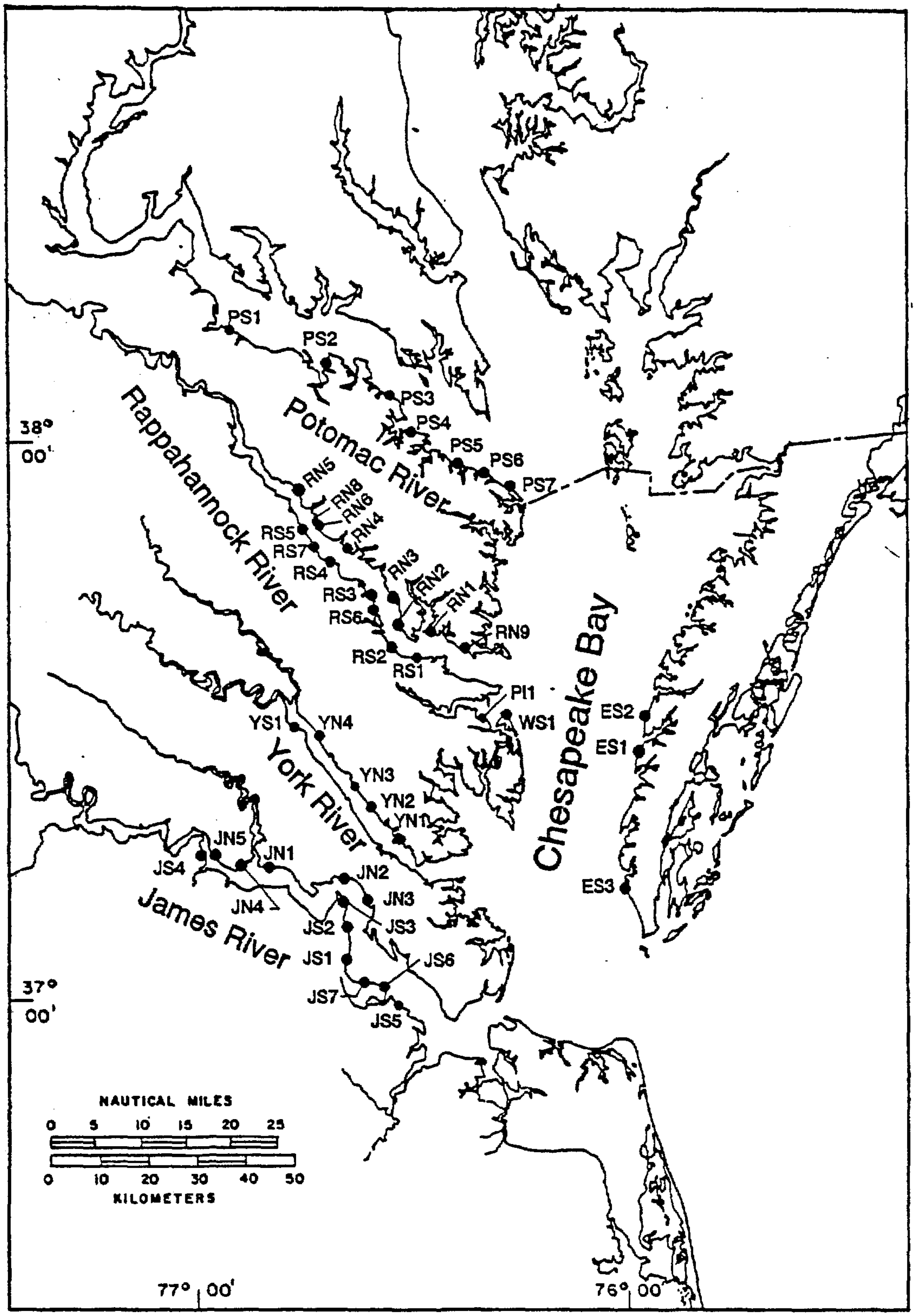


Figure 1. Site Locations.

Table 1. Site Information

Site	County	Reach No.*	Reach Length (ft)*	Erosion Rate (ft/yr)*	Volume Eroded (cy/ft/yr)*	Landuse	Sampling Date	Bank Height (ft)
PS1 - Potomac South 1	Westmoreland	12	26700	3.5	7.87	active farm	8/14/91	18.0
PS2 - Potomac South 2	Westmoreland	34	5800	2.8	0.74	active farm	8/14/91	17.0
PS3 - Potomac South 3	Westmoreland	46	5300	4.2	0.78	active farm	8/28/91	15.5
PS4 - Potomac South 4	Northumberland	55	5000	2.0	0.39	active farm	8/14/91	8.0
PS5 - Potomac South 5	Northumberland	74	7500	3.8	1.30	fallow farm, new rural residential	8/28/91	8.5
PS6 - Potomac South 6	Northumberland	76	42500	4.9	1.83	wooded	8/28/91	12.0
PS7 - Potomac South 7	Northumberland	76	42500	4.9	1.83	fallow farm	9/11/91	8.0
RN1 - Rappahannock North 1	Lancaster	178	2600	1.6	0.63	wooded	8/13/91	16.8
RN2 - Rappahannock North 2	Lancaster	207	12200	2.8	No Data	active farm	8/7/91	23.0
RN3 - Rappahannock North 3	Lancaster	213	6300	1.6	0.04	wooded	8/7/91	19.5
RN4 - Rappahannock North 4	Richmond	239	13400	2.6	0.49	active farm	8/7/91	10.0
RN5 - Rappahannock North 5	Richmond	255	20400	2.4	1.08	rural residential	8/6/91	16.0
RN6 - Rappahannock North 6	Richmond	248	4100	1.8	0.69	wooded	8/7/91	8.0
RN8 - Rappahannock North 8	Richmond	248	4100	1.8	0.69	active farm	8/7/91	7.0
RN9 - Rappahannock North 9	Lancaster	160	3800	{0.7}	No Data	wooded, rural residential	8/13/91	48.0
RS1 - Rappahannock South 1	Middlesex	107	9500	1.6	1.20	active farm with vegetated buffer	10/9/91	25.0
RS2 - Rappahannock South 2	Middlesex	106	15800	1.9	1.53	fallow farm with wooded fringe	10/9/91	30.0

Table 1. Site Information (Continued)

Site	County	Reach No.*	Reach Length (ft)*	Erosion Rate (ft/yr)*	Volume Eroded (cy/ft/yr)*	Landuse	Sampling Date	Bank Height (ft)
RS3 - Rappahannock South 3	Middlesex	85	4700	2.1	0.56	fallow farm	8/6/91	10.0
RS4 - Rappahannock South 4	Essex	70	27400	3.3	2.51	active farm, wooded fringe	8/13/91	26.0
RS5 - Rappahannock South 5	Essex	69	10200	{0.7}	No Data	rural residential	8/13/91	16.0
RS6 - Rappahannock South 6	Middlesex	88	8700	1.8	0.70	active farm	8/6/91	10.0
RS7 - Rappahannock South 7	Essex	70	27400	3.3	2.51	rural residential, wooded	8/6/91	27.0
YN1 - York North 1	Gloucester	88	4500	0.4	0.05	wooded	3/25/91	7.0
YN2 - York North 2	Gloucester	94	3400	{0.7}	No Data	wooded	3/25/91	21.5
YN3 - York North 3	Gloucester	97	3600	{0.7}	+0.08	residential	3/25/91	26.0
YN4 - York North 4	King & Queen	114	5800	1.6	0.30	logged, scrub wooded	3/25/91	3.5
YS1 - York South 1	New Kent	6	15700	1.4	0.53	logged in '85, wooded	3/25/91	16.0
JN1 - James North 1	James City	307	2800	0.7	No Data	active farm	4/17/91	11.0
JN2 - James North 2	James City	293	23100	{0.7}	No Data	wooded	4/17/91	23.0
JN3 - James North 3	James City	291	9600	1.2	0.23	wooded	4/17/91	22.5
JN4 - James North 4	Charles City	341	6600	{0.7}	No Data	active farm, wooded fringe	4/22/91	12.0
JN5 - James North 5	Charles City	343	6300	{0.7}	No Data	wooded	4/22/91	20.0
JS1 - James South 1	Isle of Wight	202	20700	1.2	0.96	wooded	4/22/91	19.0
JS2 - James South 2	Isle of Wight	201	5600	1.9	0.36	wooded	4/22/91	24.0

Table 1. Site Information (Continued)

Site	County	Reach No.*	Reach Length (ft)*	Erosion Rate (ft/yr)*	Volume Eroded (cy/ft/yr)*	Landuse	Sampling Date	Bank Height (ft)
JS3 - James South 3	Surry	197	13200	2.8	0.21	wooded	4/22/91	3.0
JS4 - James South 4	Prince George	173	2400	1.4	1.09	active farm	4/22/91	13.0
JS5 - James South 5	Isle of Wight	209	700	0.7	0.02	wooded	4/24/91	22.0
JS6 - James South 6	Isle of Wight	205	36800	3.8	2.84	active farm	8/27/91	20.0
JS7 - James South 7	Isle of Wight	204	19900	0.7	0.14	fallow farm, wooded fringe	8/27/91	60.0
PI1 - Piankatank 1	Mathews	34	6000	3.7	0.41	fallow farm	7/31/91	10.0
WS1 - Western Shore 1	Mathews	326	19100	7.1	1.33	rural residential, wooded	7/31/91	3.5
ES1 - Eastern Shore 1	Northampton	155	3000	1.7	0.58	wooded	9/12/91	11.0
ES2 - Eastern Shore 2	Northampton	152	9700	5.7	1.90	fallow farm	9/12/91	12.0
ES3 - Eastern Shore 3	Northampton	194	16500	2.3	0.26	fallow farm	9/12/91	13.0

* from Shoreline Erosion in Tidewater Virginia.

{0.7} average Bay-wide erosion rate from Shoreline Erosion in Tidewater Virginia.

\+ indicates an accretional reach in volume eroded column.

III. METHODOLOGY

Laboratory Analyses

Laboratory analyses were conducted by the Virginia Institute of Marine Science sediment and water quality labs. The water quality lab uses EPA approved procedures.

Nutrient Analyses

The total nitrogen measured included nitrate nitrogen and total Kjeldahl nitrogen (TKN; includes ammonia and organic forms of nitrogen). Total nitrogen analysis was conducted using 10 to 20 mg samples of air-dried, ground soil. Each soil sample was analyzed for total nitrogen using a Carlo Erba NA1500 C/N Analyzer. The mean detection limit for total nitrogen was 0.18 mg/g. Total nitrogen analysis procedures can be found in the Carlo Erba Strumentazione Carbon Nitrogen Analyzer 1500 Instruction Manual (1986).

Phosphorus measured included total phosphorus and inorganic phosphorus (orthophosphate). The procedures used air-dried, homogenized, ground soil samples. The inorganic phosphorus procedure involved an HCl and H_2SO_4 extraction of approximately 1 g soil samples. The total phosphorus procedure involved combustion of approximately 1 g samples at 475 °C for 5 hours, followed by HCl extraction of phosphorus. For both phosphorus procedures, sample extracts were filtered through Whatman G/F glass fiber filters and then analyzed using a continuous flow analyzer. The mean detection limit for total phosphorus was 0.01 mg/g and 0.001 mg/g for inorganic phosphorus. Phosphorus procedures were taken from the following reference manuals: "Laboratory Procedure for the Soil Testing and Plant Analysis Laboratory" (1988) and Methods for Chemical Analysis of Water and Wastes (U.S Environmental Protection Agency, 1974).

Grain Size Analysis

The sediment samples were split, wet sieved and separated into gravel, sand, silt and clay fractions. To determine a weight percent, the gravel fraction (material coarser than 2.0 mm) was dried and weighed. The sand fraction (0.0625 to 2.0 mm) was analyzed using a rapid sediment analyzer (RSA) to determine the grain size distribution and weight percent. The weight percentages of the silt and clay fractions (material finer than 0.0625 mm) were measured according to standard pipette methods.

<u>Nutrient Loading Rates</u>

Nutrient loading rates were calculated for each site using the following information: nutrient concentration, estimated average bulk density, bank height, horizon thickness and annual erosion rate. All of the above variables were known except bulk density. The limited scope of the study did not allow field measurements of the bulk densities of the soils sampled. Therefore, an estimated average bulk density of 93.6 lb/ft^3 (1.5 g/cm^3) was used. The bulk density value used was based on conversations with soil scientists and researchers from Virginia Polytechnic Institute and State University. Moreover, the value used was similar to the bulk densities reported in the soil surveys for some of the soils studied.

To calculate a nutrient loading rate for each site, the bank erosion volume was first calculated using the following equation:

$$V = B\ E\ W \tag{1}$$

where: V = Unit bank erosion volume (ft^3/ft-yr)
B = Bank height (ft)
E = Unit erosion rate (ft/ft-yr)
W = Unit width (ft)

Nutrient loading rates were then derived. In the following equation, a mean nutrient concentration for each bank was calculated by summing the weighted nutrient concentrations for each soil horizon. The mean nutrient concentration for the bank was then multiplied by the bulk density and eroded soil volume to obtain the nutrient loading rate for the bank. The equation is presented as follows:

$$R = V D \sum \left(\frac{H N}{B}\right) \quad (2)$$

where: R = Nutrient loading rate (lbs/ft-yr)

B = Bank height (ft)

D = Bulk density (93.6 lb/ft^3)

H = Horizon thickness (ft)

N = Nutrient concentration (mg/g) converted to English units (lb/ton)

V = Unit bank erosion volume (ft^3/ft-yr)

Nutrient Loading Concentrations

The term "nutrient loading concentration" refers to the amount of a given nutrient in pounds, per ton of soil. The mean loading concentrations for total nitrogen and total phosphorus were used in the previous research to estimate the amount of nitrogen and phosphorus entering the Chesapeake Bay from shoreline erosion. (In the previous report, the term "nutrient loading factor" was used, however the term "nutrient loading concentration" is more descriptive since the values are reported in pounds per ton.) Similar nutrient loading concentrations are used in the Chesapeake Bay Agricultural BMP Cost-Share program to determine the effectiveness of best management practices. The loading concentrations were calculated using the following formula:

$$C = \frac{R}{S} \quad (3)$$

where: C = Nutrient loading concentration (lb/ton)

R = Nutrient loading rate (lbs/ft-yr)

S = Sediment loss (tons/ft-yr)

The sediment loss was calculated using the volume lost (lbs/ft-yr), a bulk density of 93.6 lb/ft^3 and a conversion factor for a ton (2000 lbs). The loading concentrations also represent a weighted avérage for each site.

Sediment and Nutrient Loading Rates per Acre per Year

Nutrient loading rates for upland erosion have traditionally been expressed in lbs/acre/yr. To calculate an equivalent rate for shoreline erosion, the area contained in one acre (43,560 ft^2/acre) was divided by the shoreline erosion rate (ft/yr) to obtain an equivalent length or:

$$L = \frac{43560 \frac{ft^2}{acre}}{ET} \tag{4}$$

Where: L = Length of shoreline (ft/acre)
E = Erosion rate (ft/yr)
T = Time (1 yr)

The equivalent length is then multiplied by the bank height (B) and erosion rate (E) to obtain the soil loss per acre per year (equation 5):

$$V = L\ E\ B \tag{5}$$

where: V = Volume eroded (ft^3/acre-yr)
L = Length (ft/acre)
E = Erosion rate (ft/yr)
B = Bank height (ft)

Using a soil bulk density of 93.6 lb/ft^3, and converting from pounds to tons, the volume of eroded soil can be converted to mass (tons). The nutrient contribution per acre of shoreline can be calculated as the product of the nutrient loading concentration times the soil volume eroded times the bulk density.

Figure 2 illustrates the comparison of soil loss from upland erosion versus shoreline erosion. Assume a site such as PS1 in Westmoreland County with an average shoreline erosion rate of 3.5 feet per year (Byrne and Anderson, 1977). A representative acre (43,560 ft^2) of shoreline therefore has a width of 3.5 feet and length of 12,446 feet. The total volume of soil lost by shoreline erosion varies with the bank height at the shore. The bank height at PS1 is 18.0 feet from the base to the top. The soil loss calculated using equations 4 and 5 is 36,696 tons/acre-yr. In contrast, the average upland erosion rate for 3 highly erodible agricultural subwatersheds in Westmoreland and Richmond Counties is 14 tons/acre-year (Brown and Price, 1988).

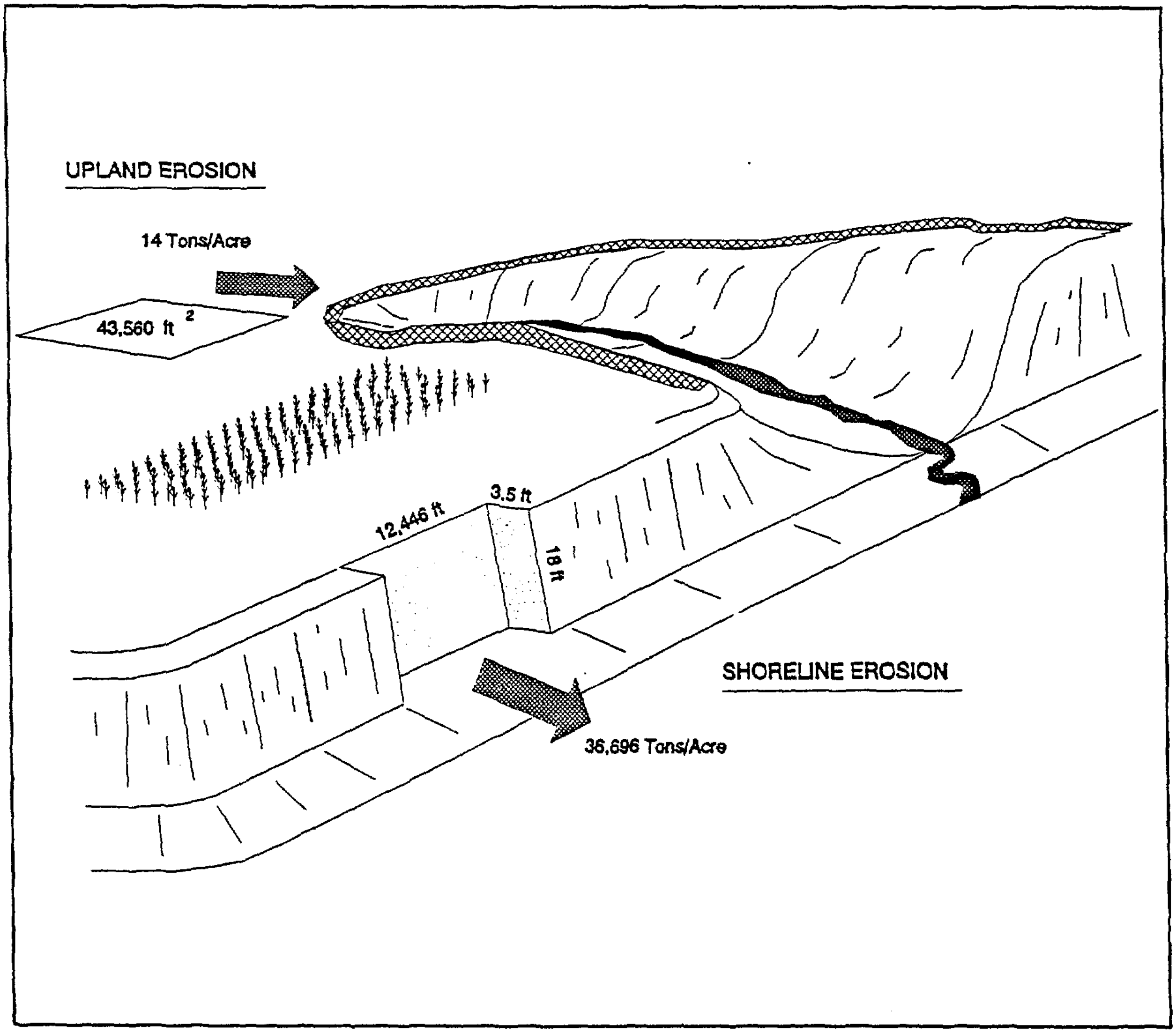


Figure 2. Illustration of Upland Erosion Versus Shoreline Erosion

IV. RESULTS

Nutrient Concentration, Grain Size and Bank Height

Grain size, inorganic phosphorus, total phosphorus and total nitrogen concentrations are plotted against bank height for each site in Figures 4 through 25. Although both total phosphorus and inorganic phosphorus were measured in Ibison et. al. (1990), total phosphorus was reported to keep the research consistent with the Chesapeake Bay Program nutrient loading estimates (Chesapeake Executive Council, 1988). In the present study, inorganic phosphorous data has been included to show the amount of immediately available phosphorus. (Inorganic phosphorus data measured in the previous research are presented in Appendix A of Ibison et. al, 1990.) Soil classification criteria used in Figures 4 through 25 are depicted in Figure 3 below:

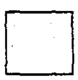
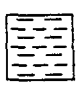
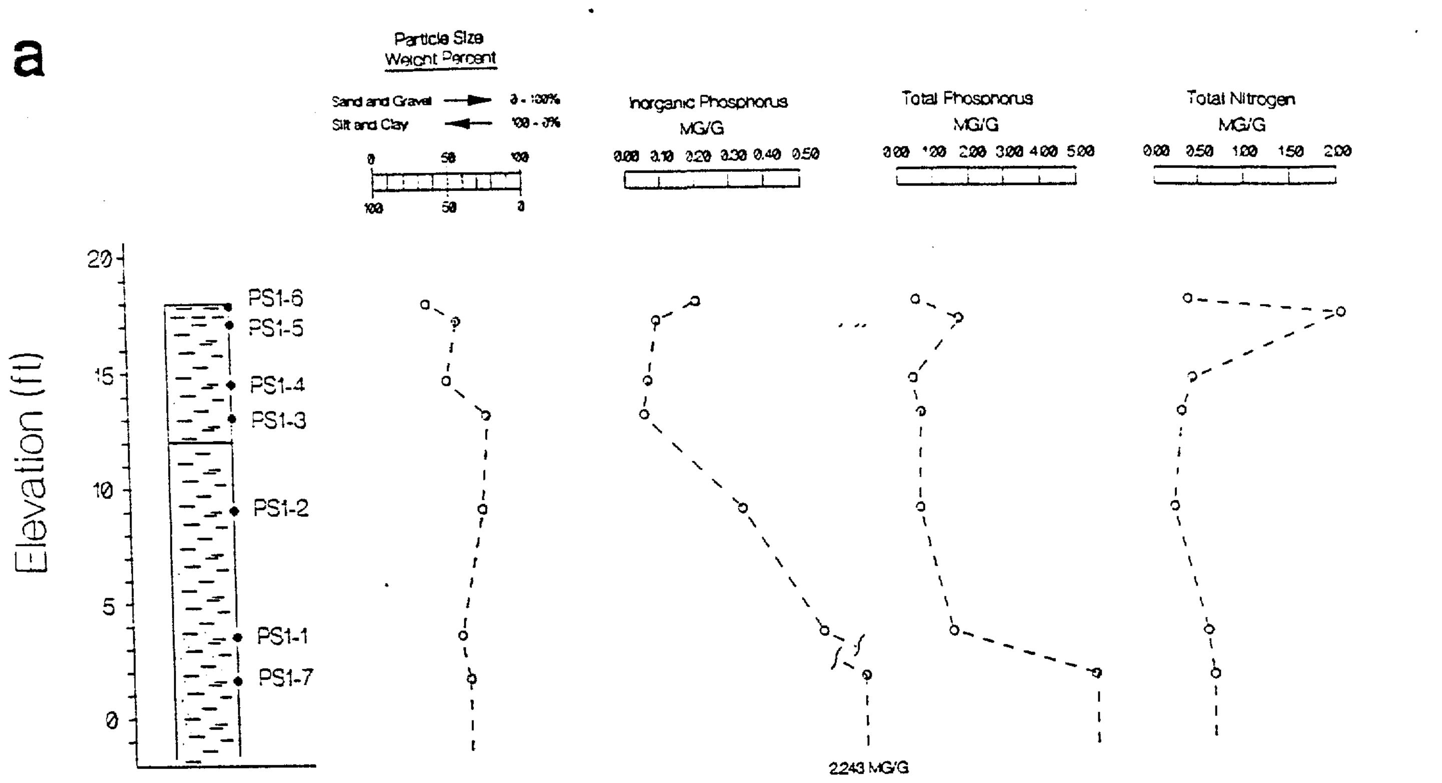
Symbol	Description	Composition
	gravel and sand	greater than 60% sand with 20% or greater gravel
	sand	greater than 80% sand less than 20% silt and clay
	silty/clayey sand	50% to 80% sand 20% to 50% silt/clay
	sandy silt/clay	50% to 80% silt/clay 20% to 50% sand
	silt/clay	greater than 80% silt/clay less than 20% sand

Figure 3. Soil Classification Criteria



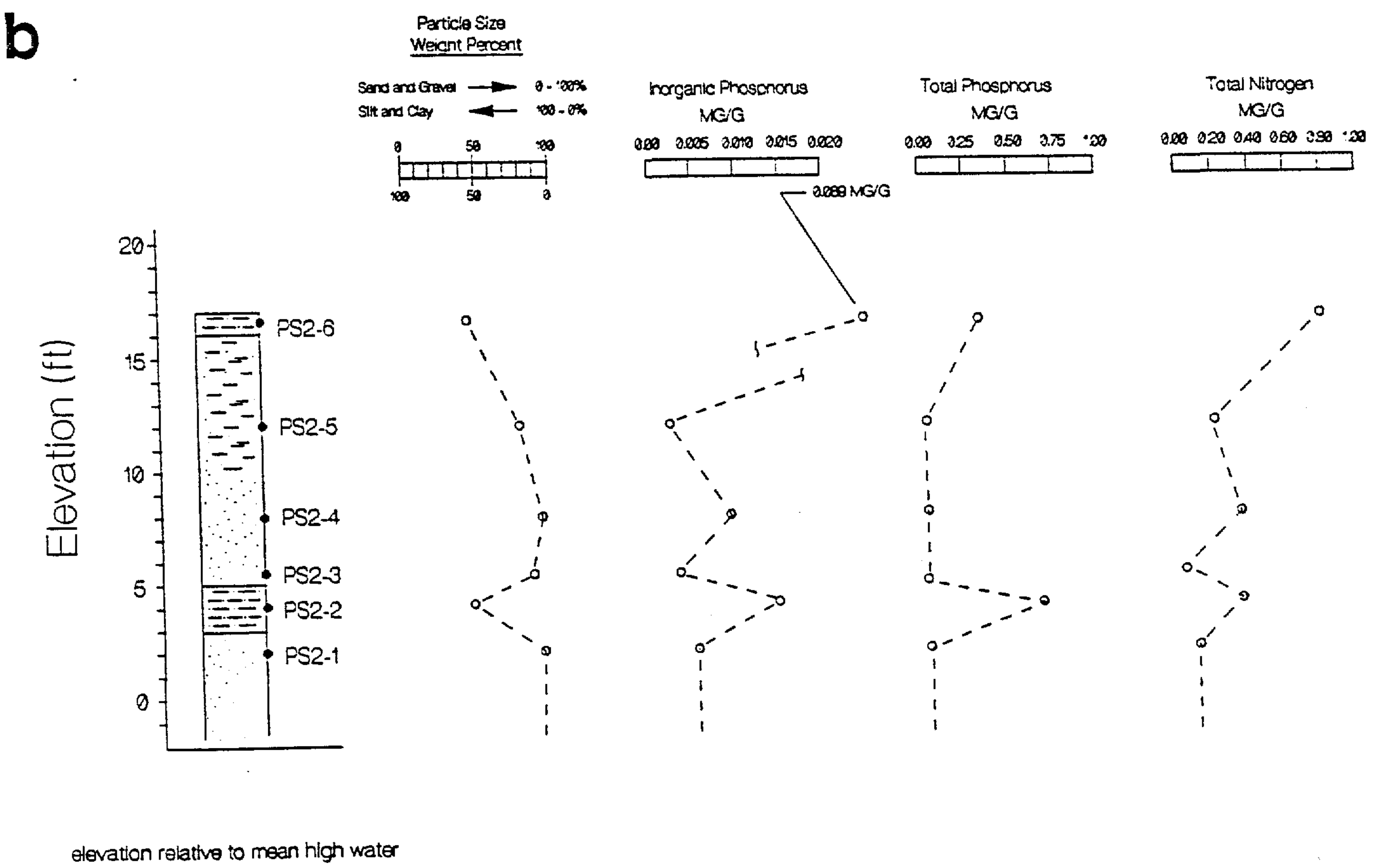


Figure 4. **Grain Size, Inorganic Phosphorus, Total Phosphorus and Total Nitrogen: a) Potomac South 1 and b) Potomac South 2.**

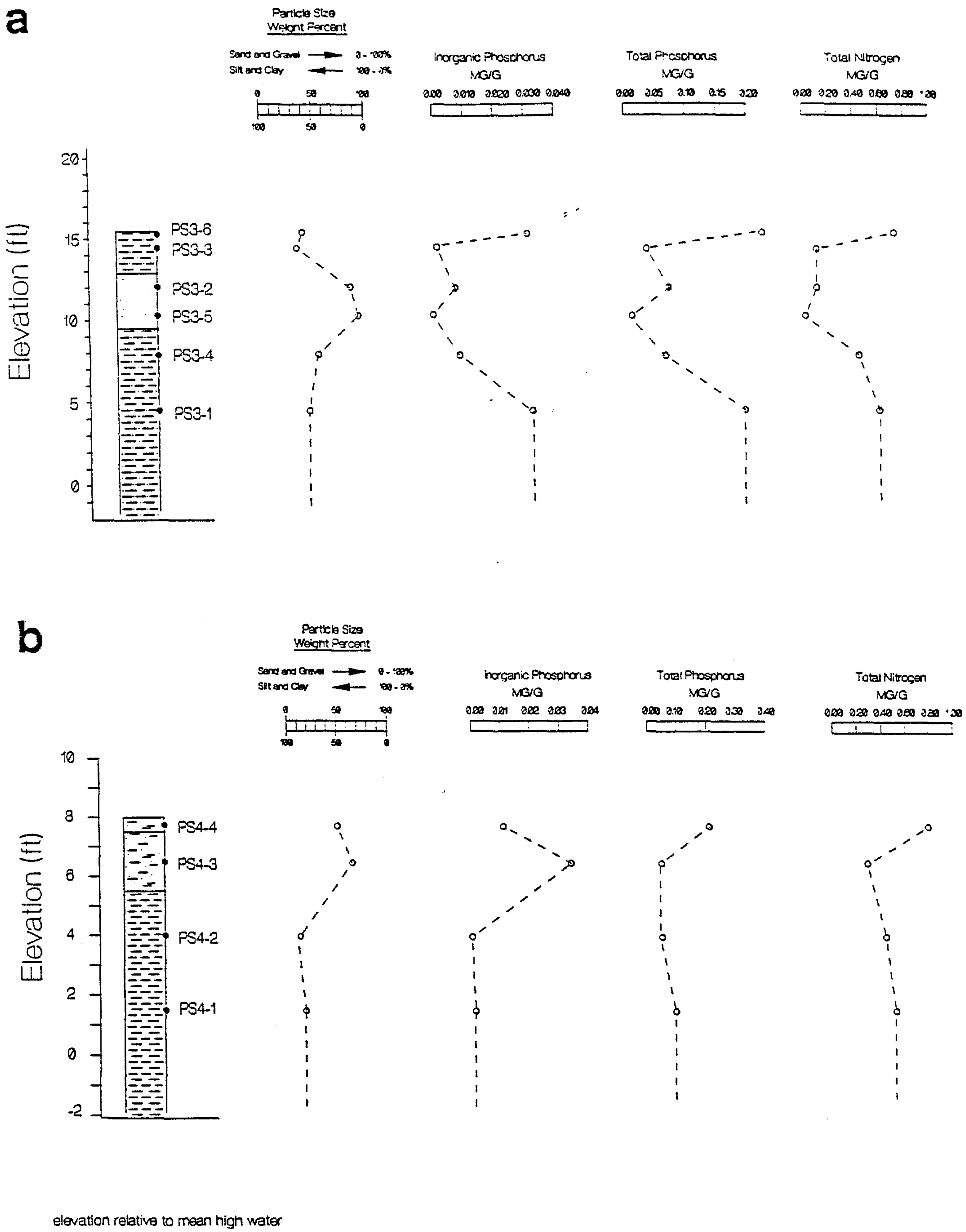


Figure 5. Grain Size, Inorganic Phosphorus, Total Phosphorus and Total Nitrogen: a) Potomac South 3 and b) Potomac South 4.

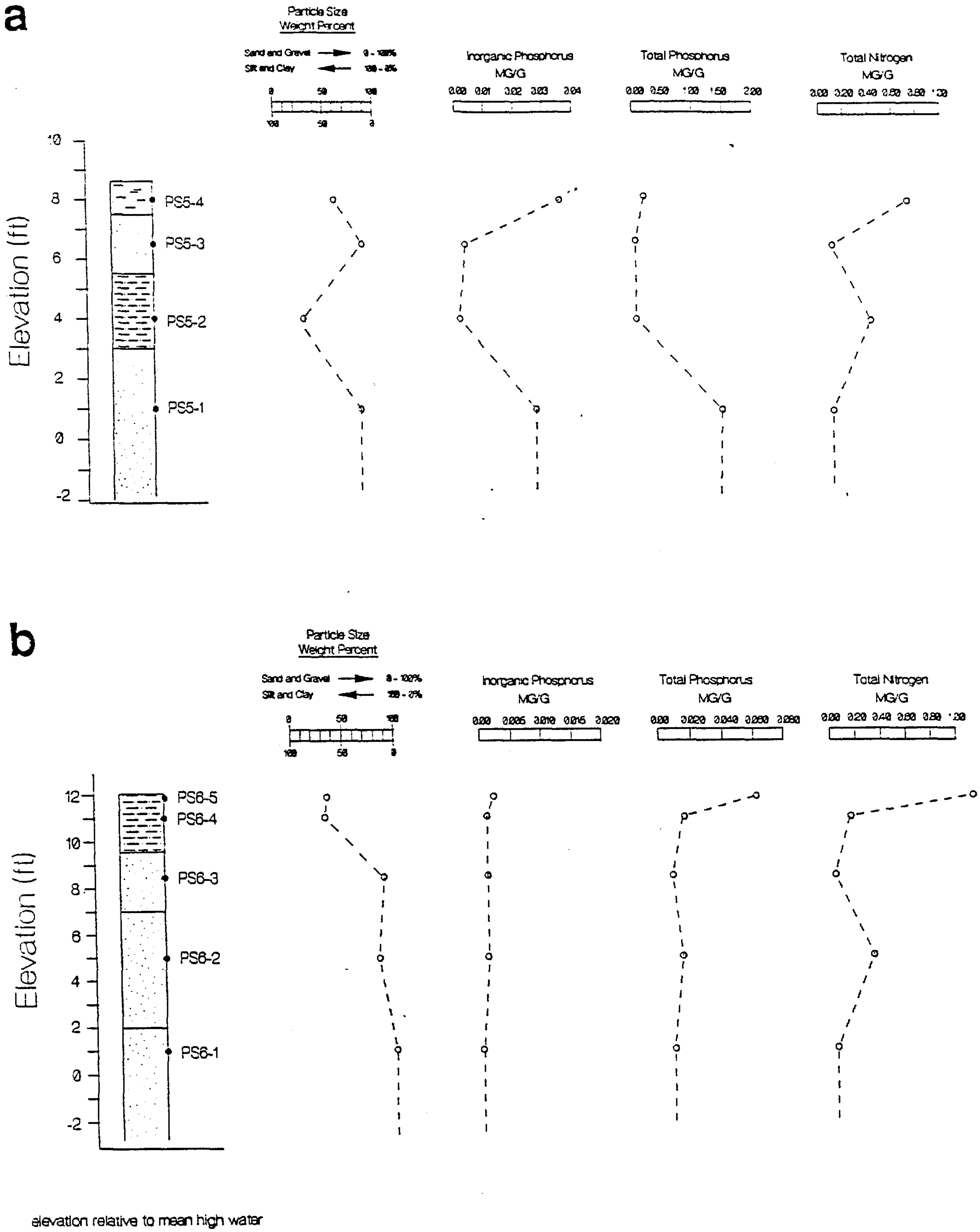


Figure 6. **Grain Size, Inorganic Phosphorus, Total Phosphorus and Total Nitrogen: a) Potomac South 5 and b) Potomac South 6.**

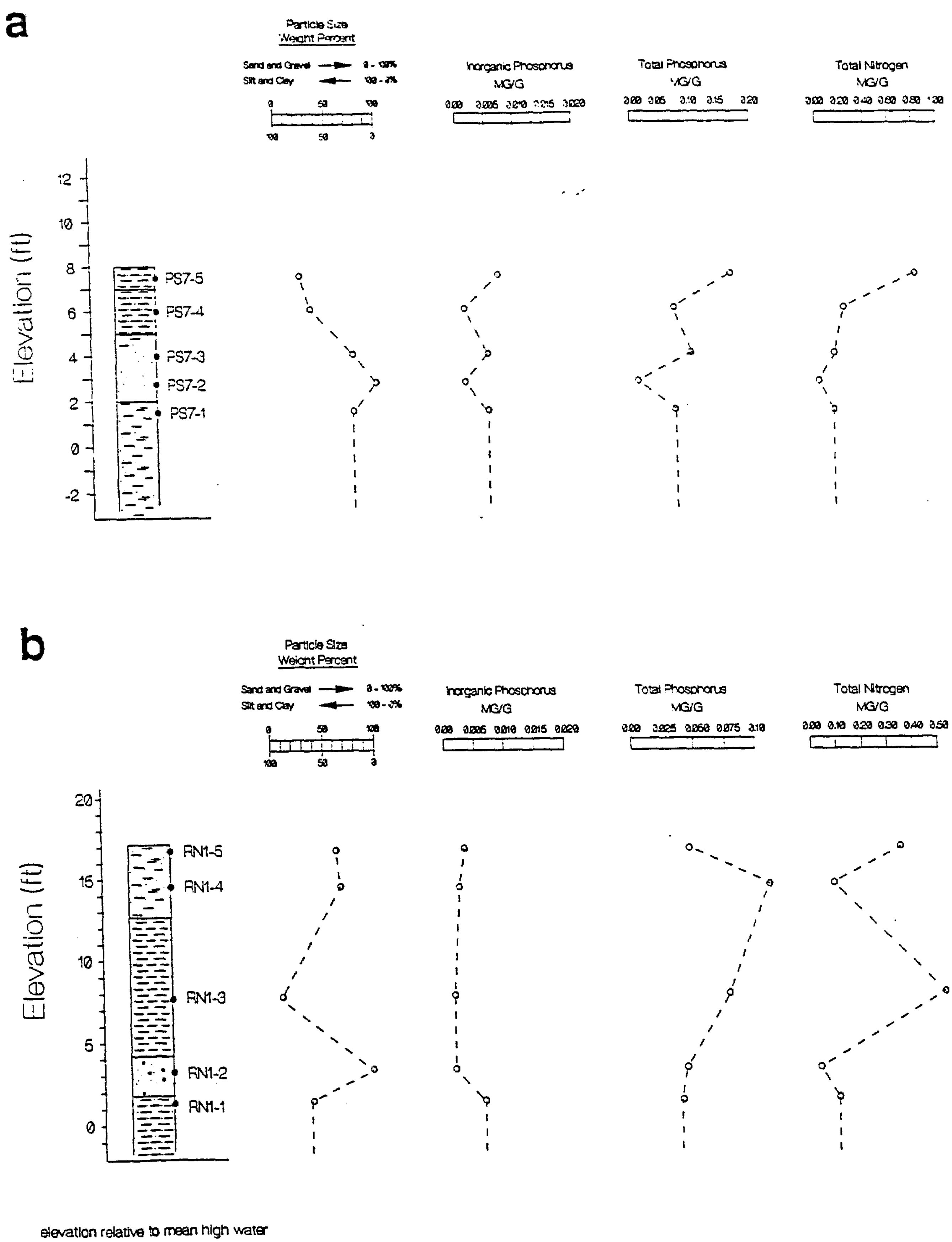


Figure 7. Grain Size, Inorganic Phosphorus, Total Phosphorus and Total Nitrogen: a) Potomac South 7 and b) Rappahannock North 1.

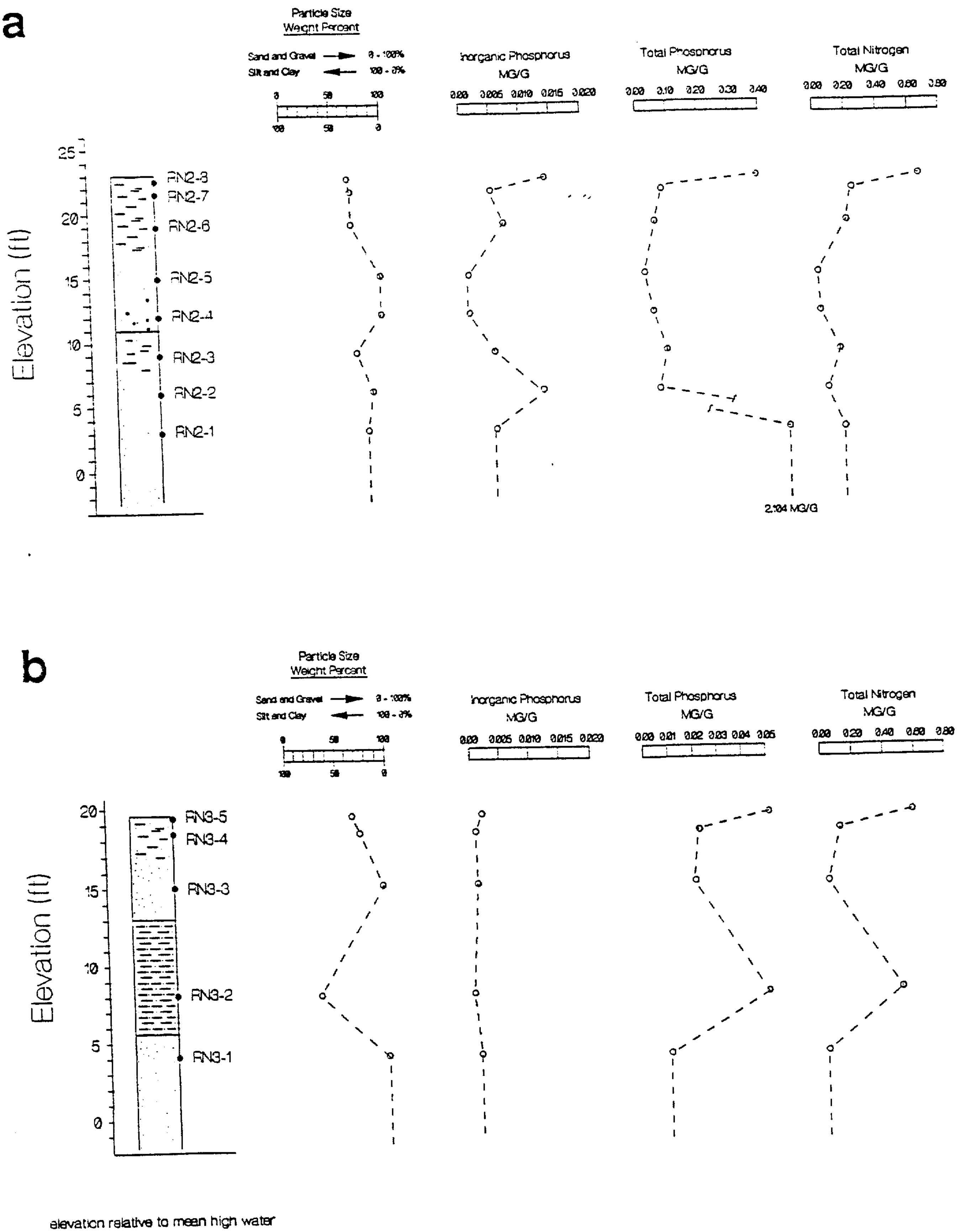
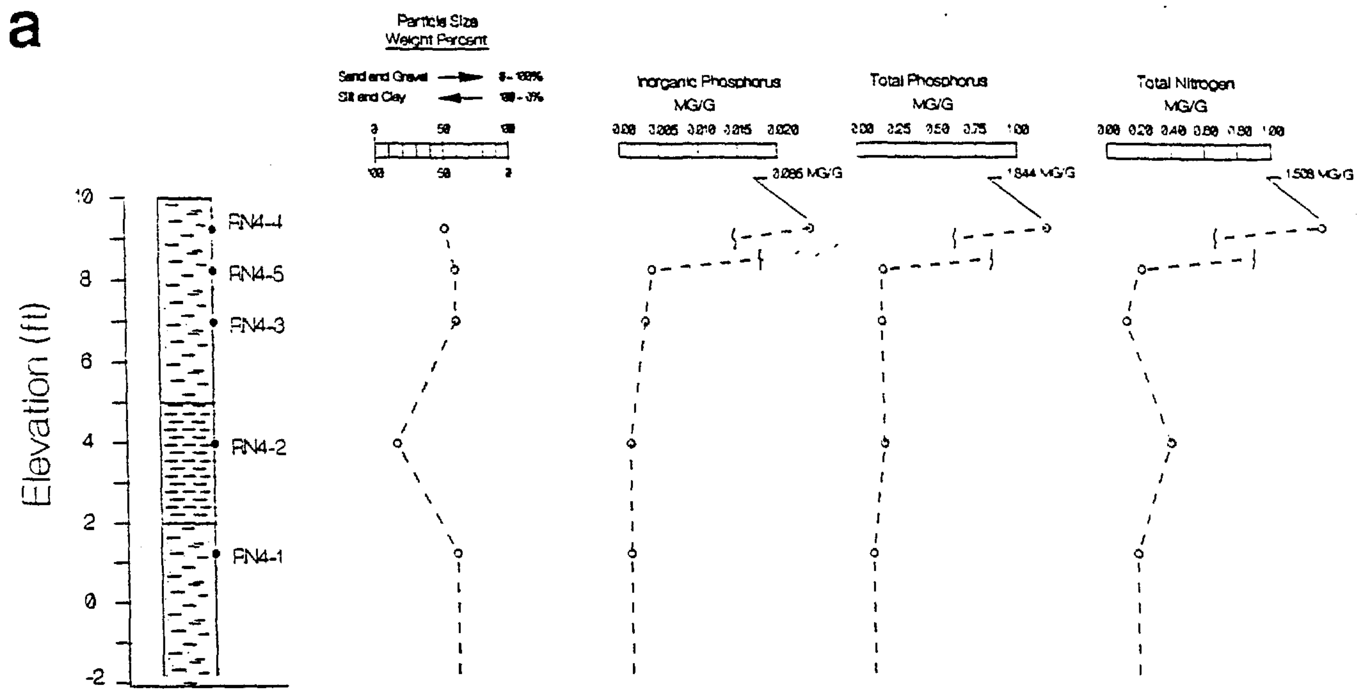
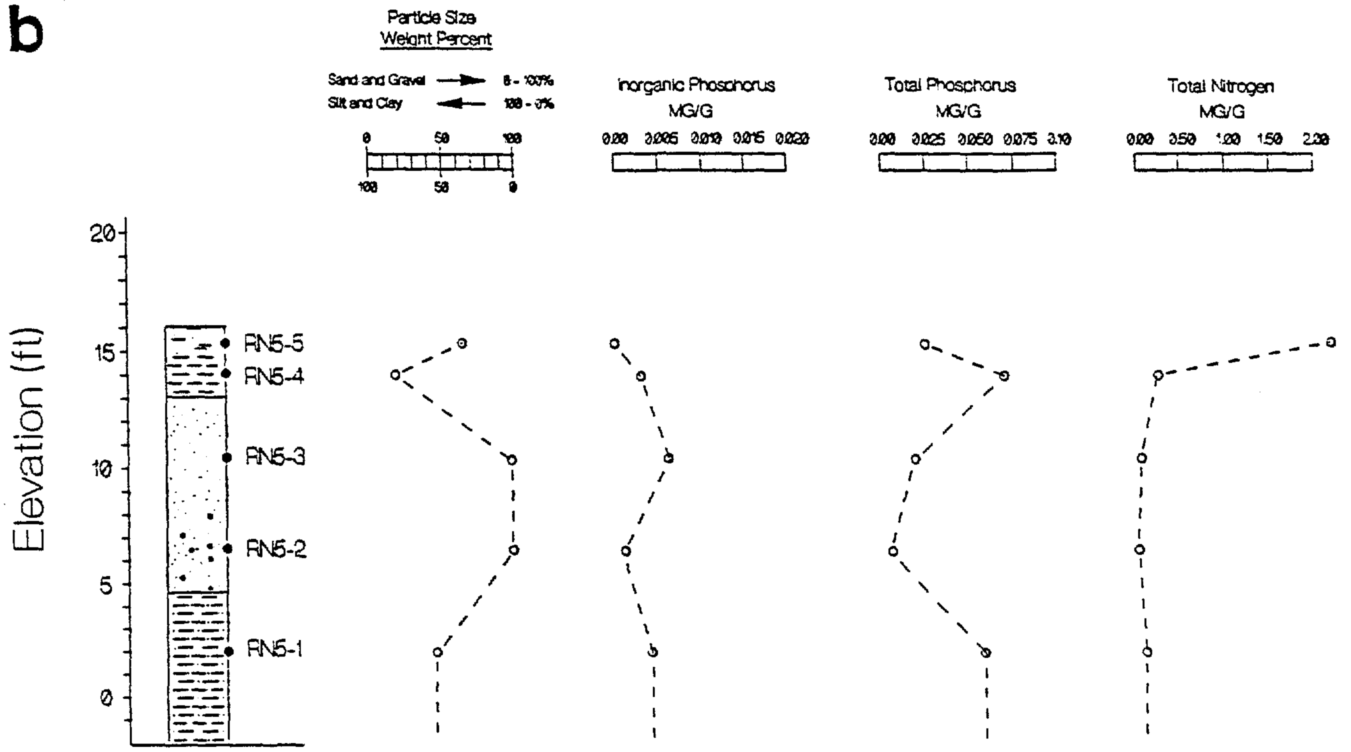


Figure 8. Grain Size, Inorganic Phosphorus, Total Phosphorus and Total Nitrogen: a) Rappahannock North 2 and b) Rappahannock North 3.





elevation relative to mean high water

Figure 9. Grain Size, Inorganic Phosphorus, Total Phosphorus and Total Nitrogen: a) Rappahannock North 4 and b) Rappahannock North 5.

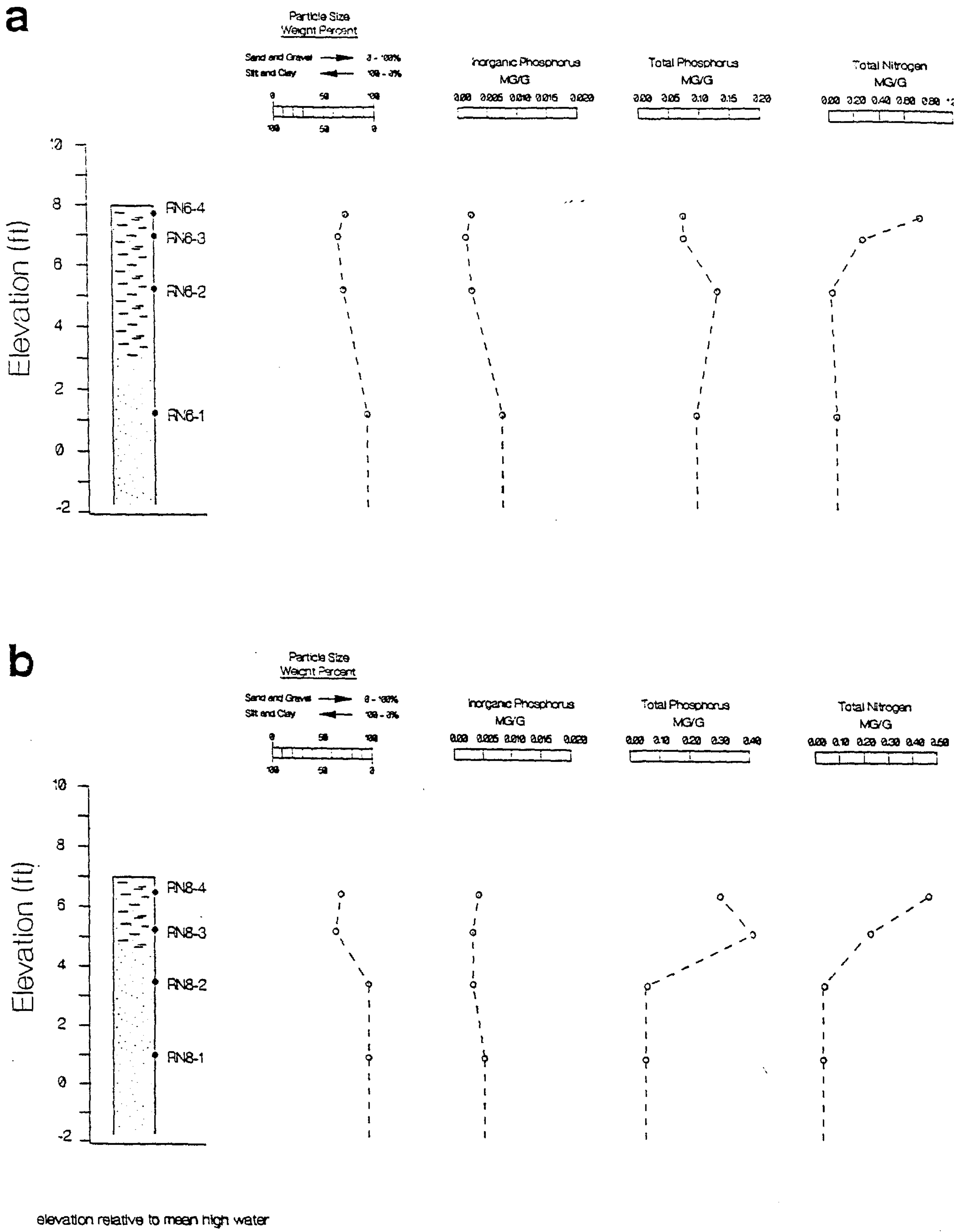


Figure 10. Grain Size, Inorganic Phosphorus, Total Phosphorus and Total Nitrogen: a) Rappahannock North 6 and b) Rappahannock North 8.

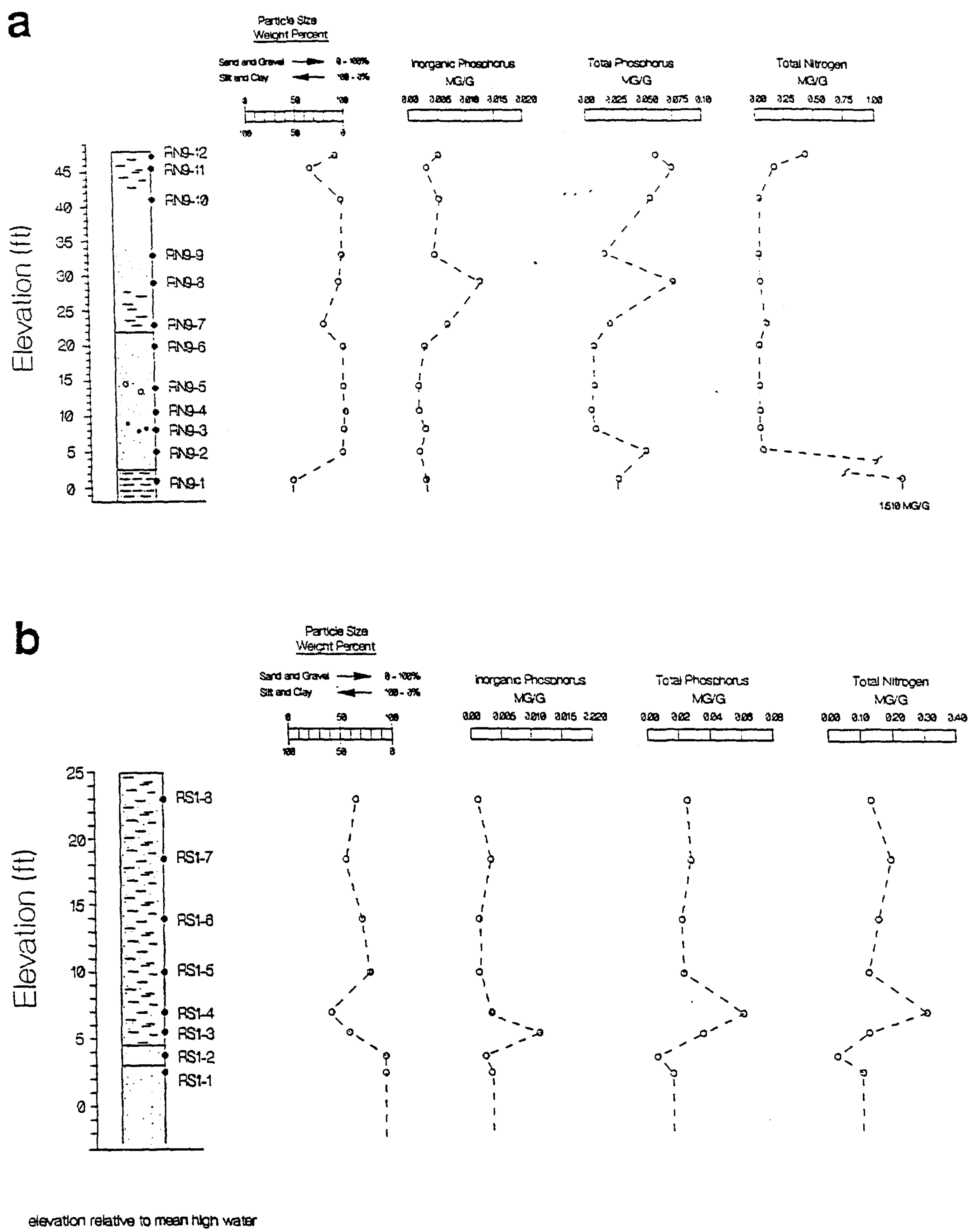


Figure 11. **Grain Size, Inorganic Phosphorus, Total Phosphorus and Total Nitrogen: a) Rappahannock North 9 and b) Rappahannock South 1.**

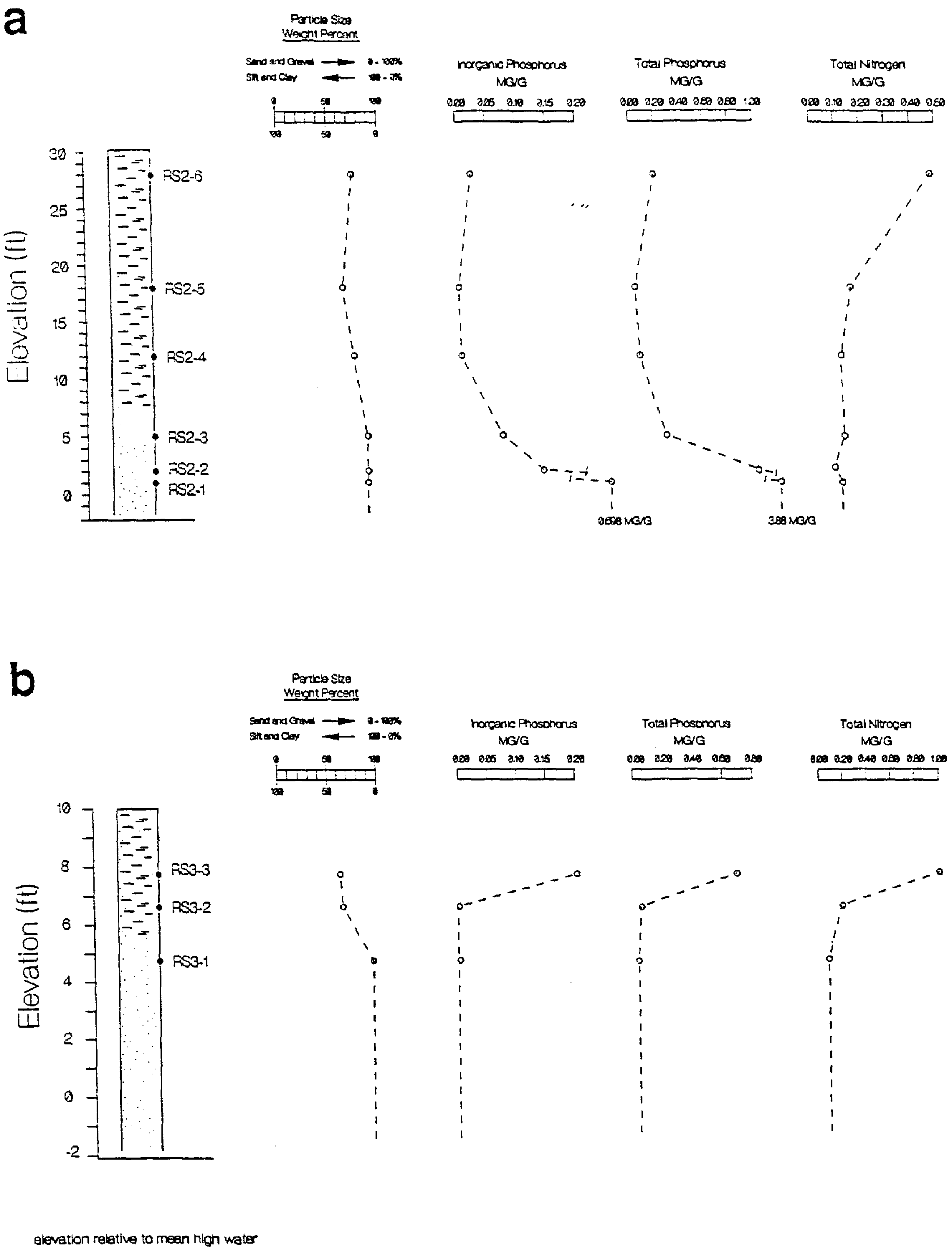
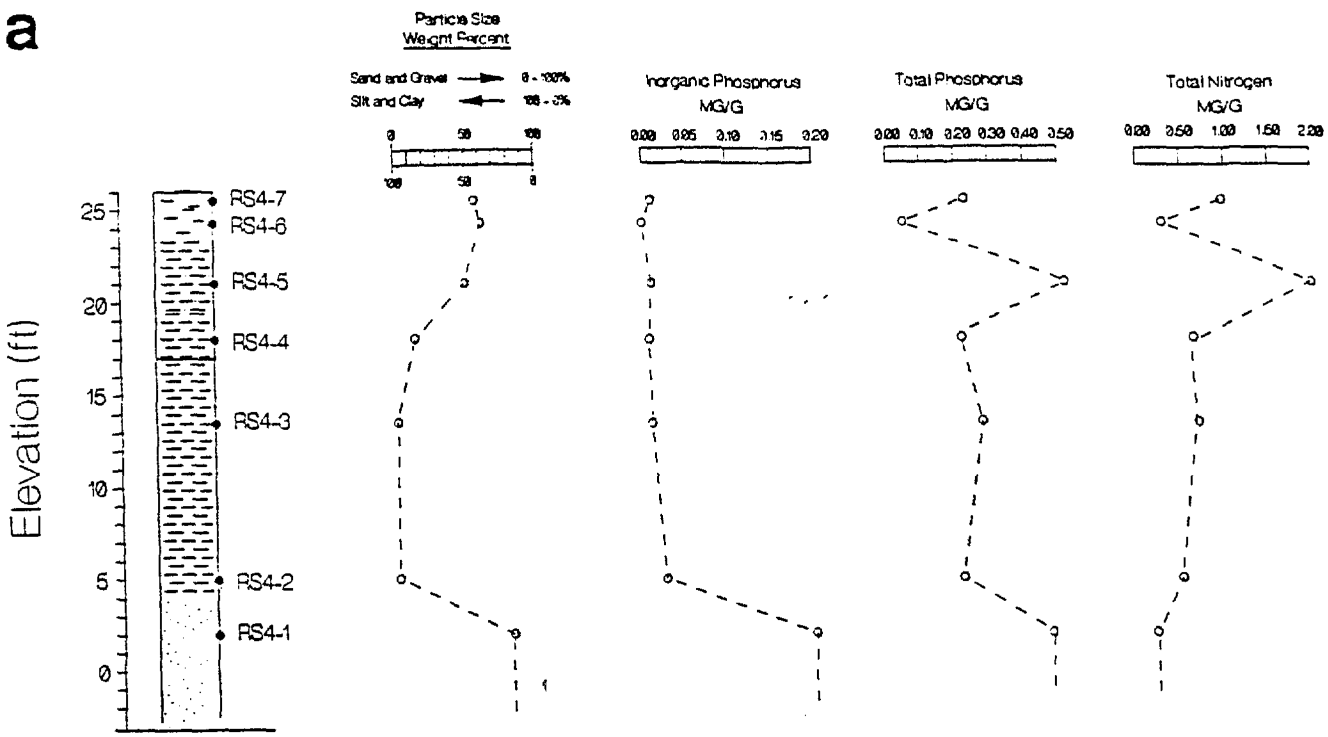


Figure 12. Grain Size, Inorganic Phosphorus, Total Phosphorus and Total Nitrogen: a) Rappahannock South 2 and b) Rappahannock South 3.



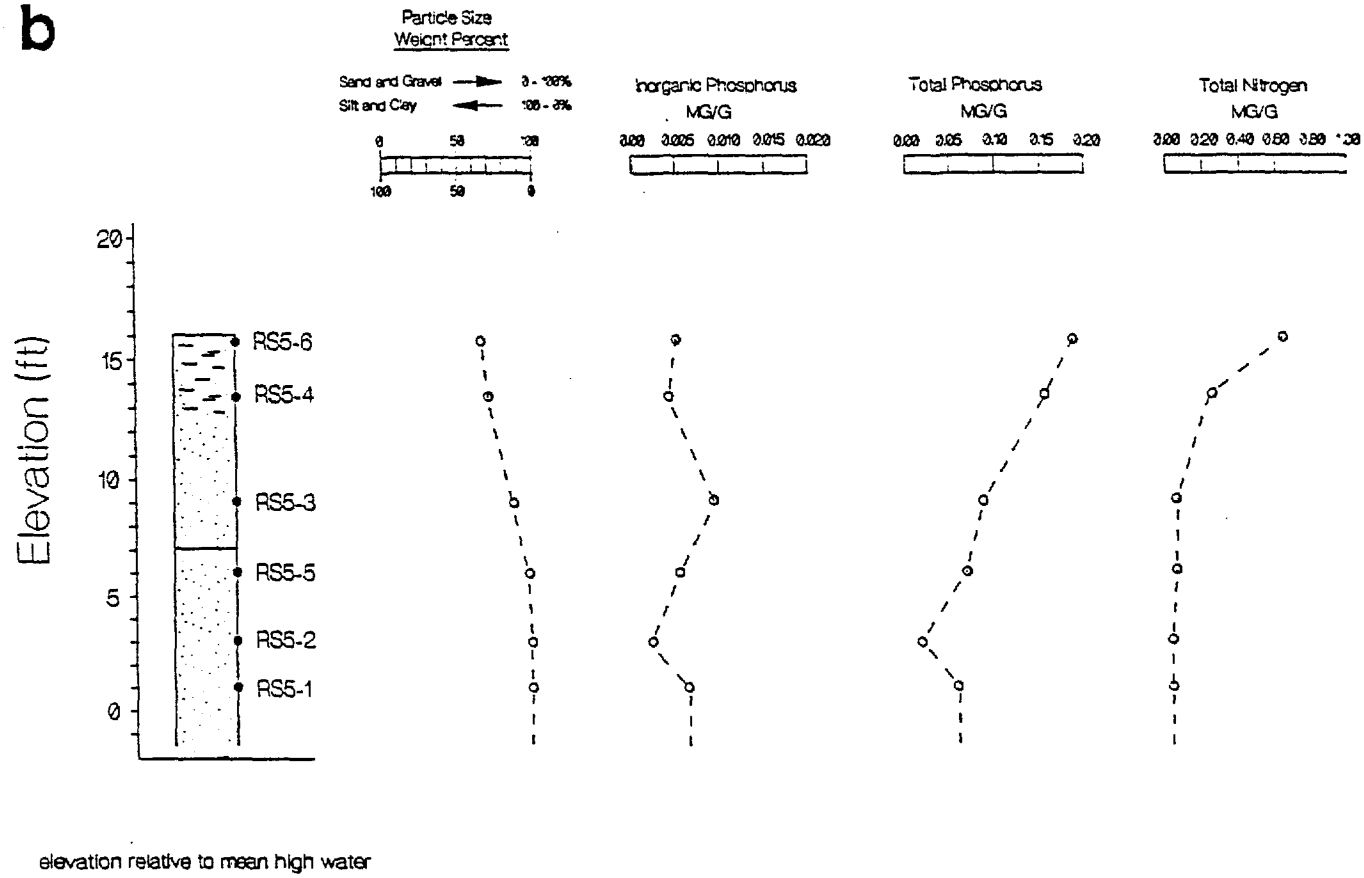


Figure 13. Grain Size, Inorganic Phosphorus, Total Phosphorus and Total Nitrogen: a) Rappahannock South 4 and b) Rappahannock South 5.

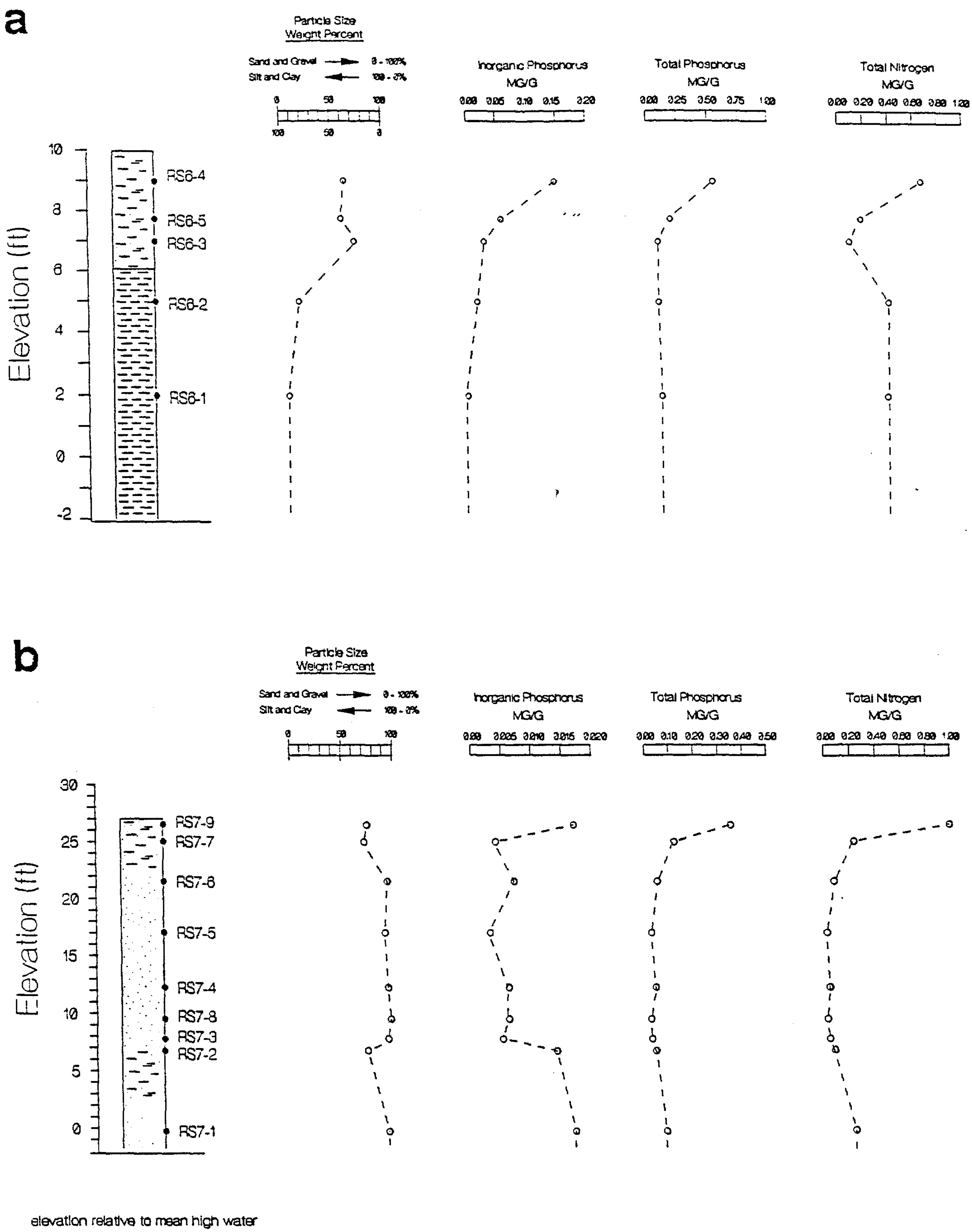


Figure 14. Grain Size, inorganic Phosphorus, Total Phosphorus and Total Nitrogen: a) Rappahannock South 6 and b) Rappahannock South 7.

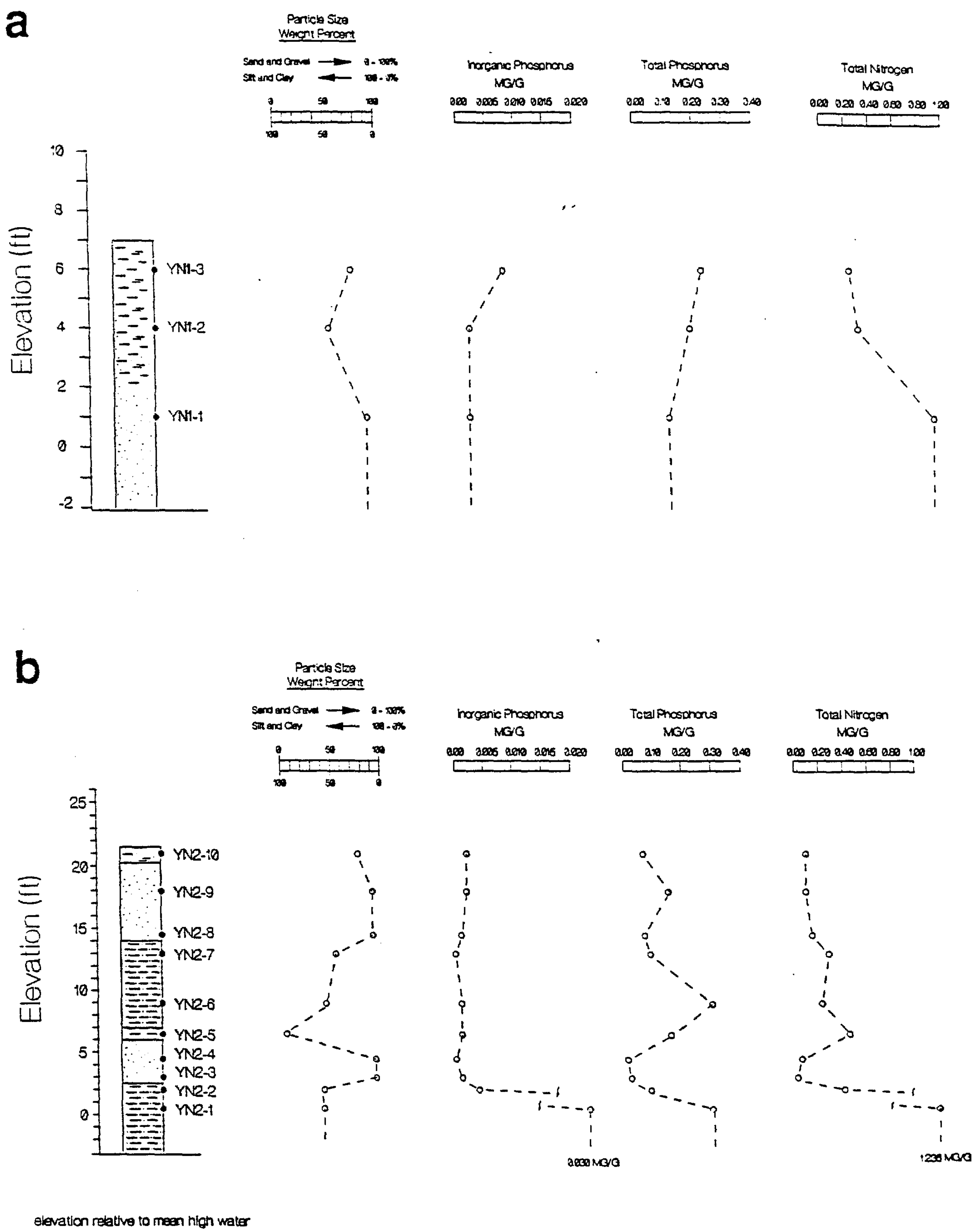


Figure 15. Grain Size, Inorganic Phosphorus, Total Phosphorus and Total Nitrogen: a) York North 1 and b) York North 2.

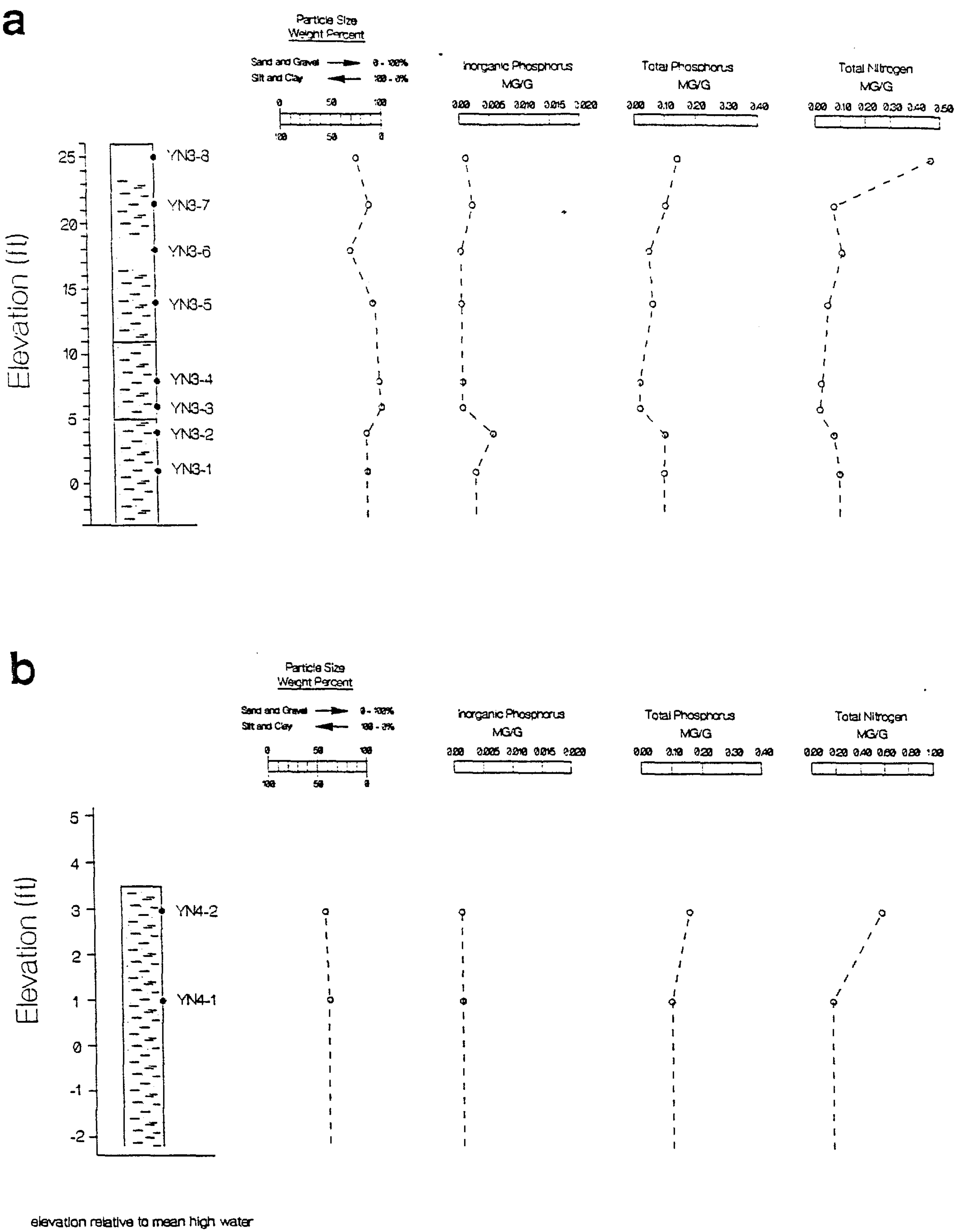


Figure 16. Grain Size, Inorganic Phosphorus, Total Phosphorus and Total Nitrogen: a) York North 3 and b) York North 4.

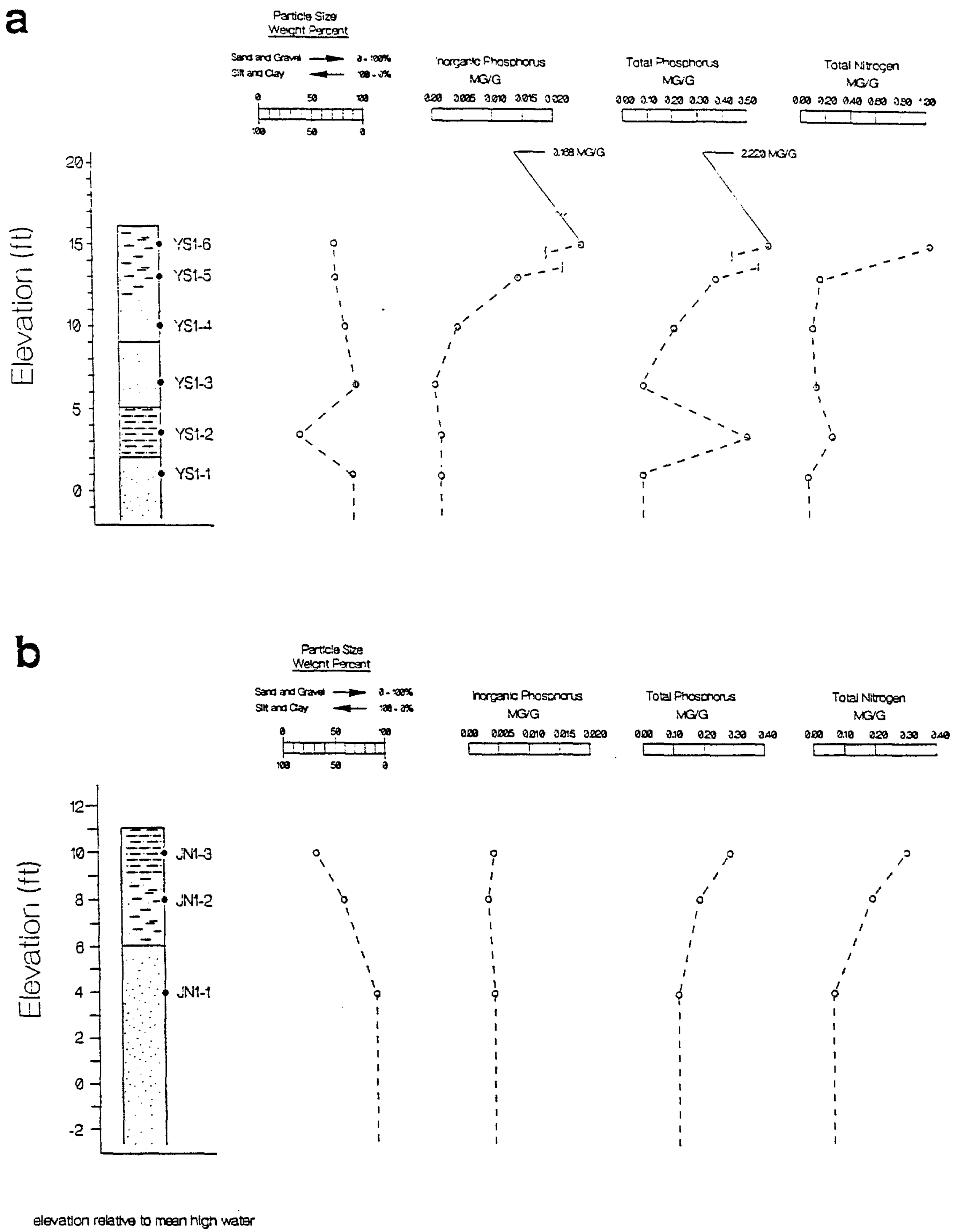


Figure 17. Grain Size, Inorganic Phosphorus, Total Phosphorous and Total Nitrogen: a) York South 1 and b) James North 1.

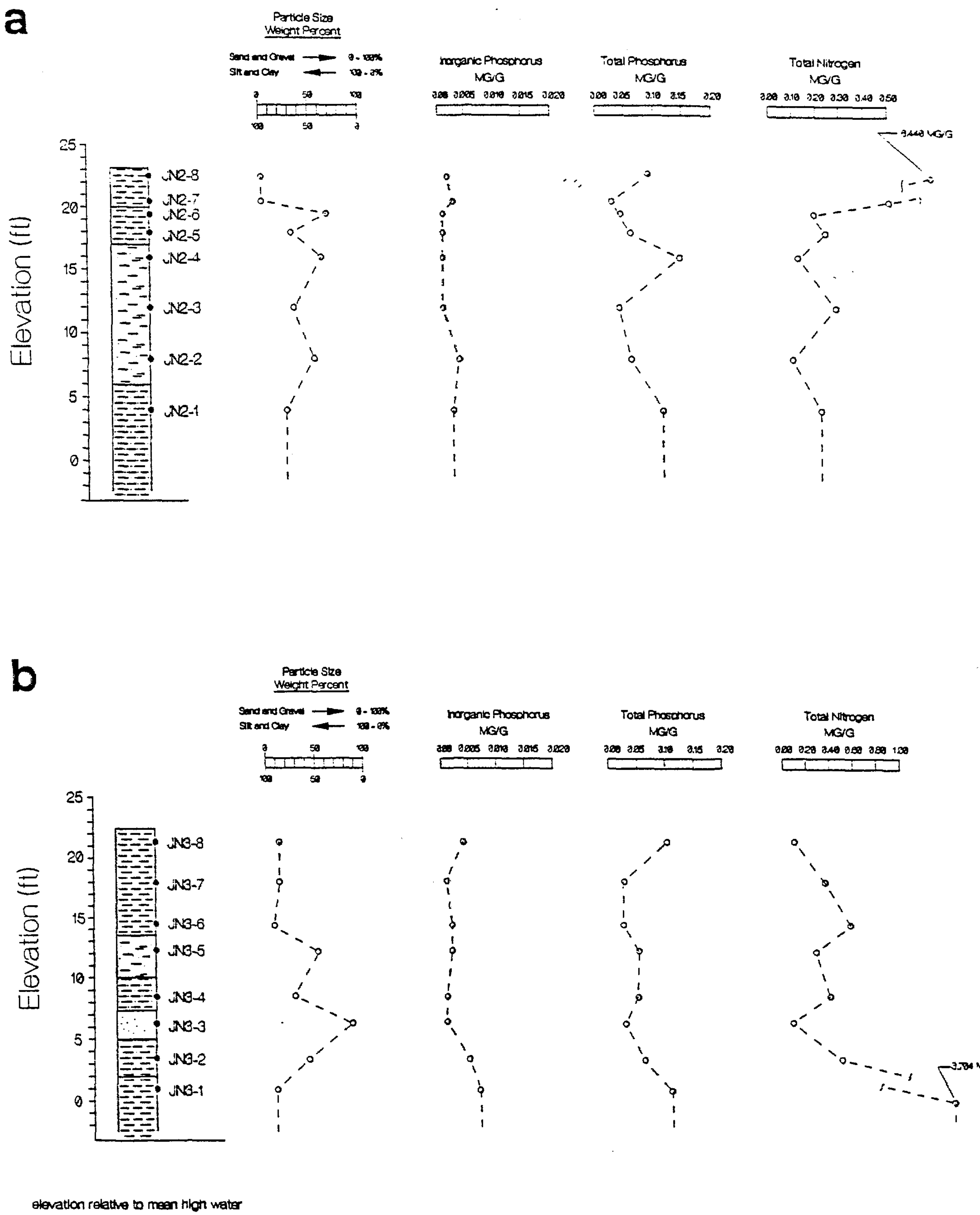


Figure 18. Grain Size, Inorganic Phosphorus, Total Phosphorus and Total Nitrogen: a) James North 2 and b) James North 3.

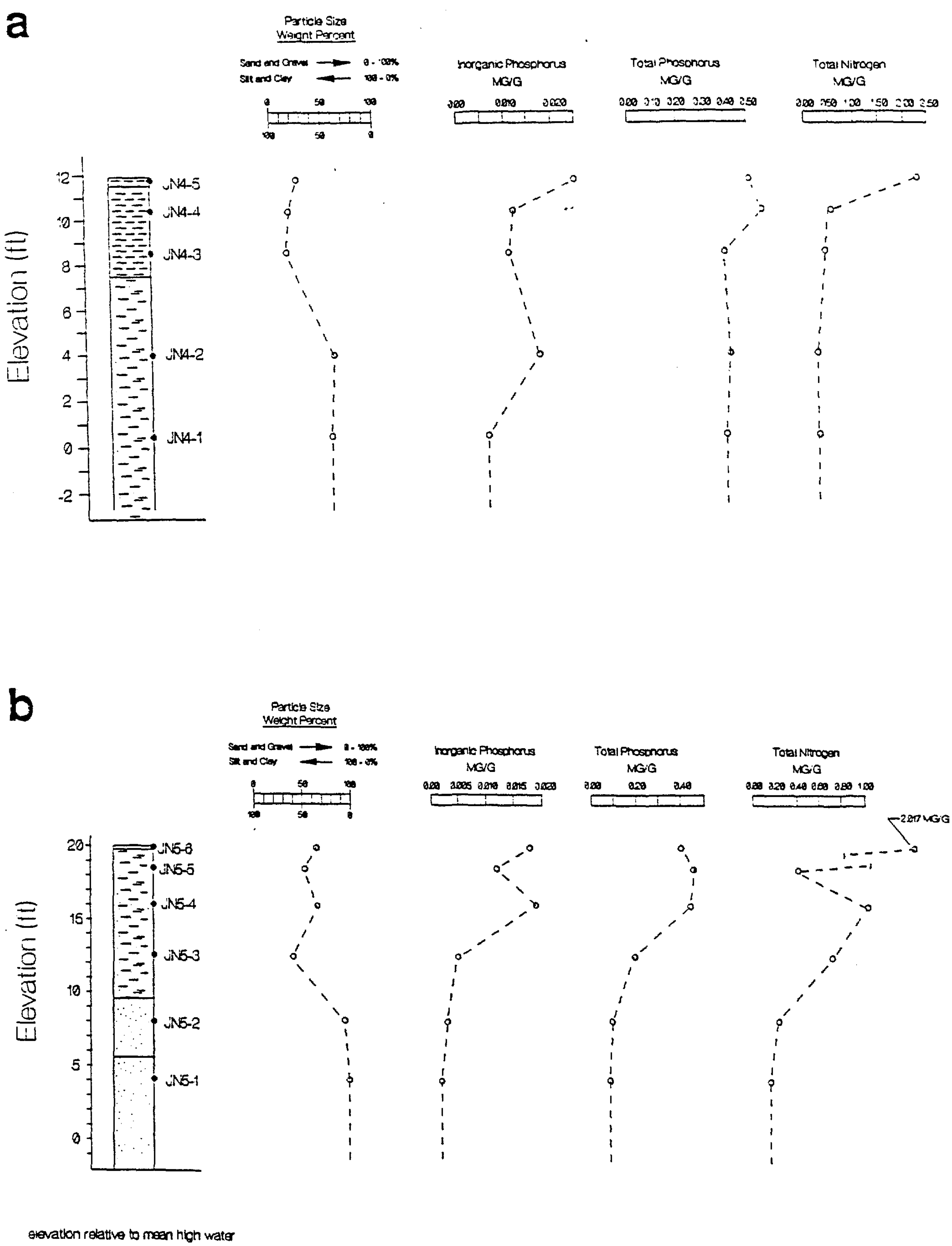


Figure 19. Grain Size, Inorganic Phosphorus, Total Phosphorus and Total Nitrogen: a) James North 4 and b) James North 5.

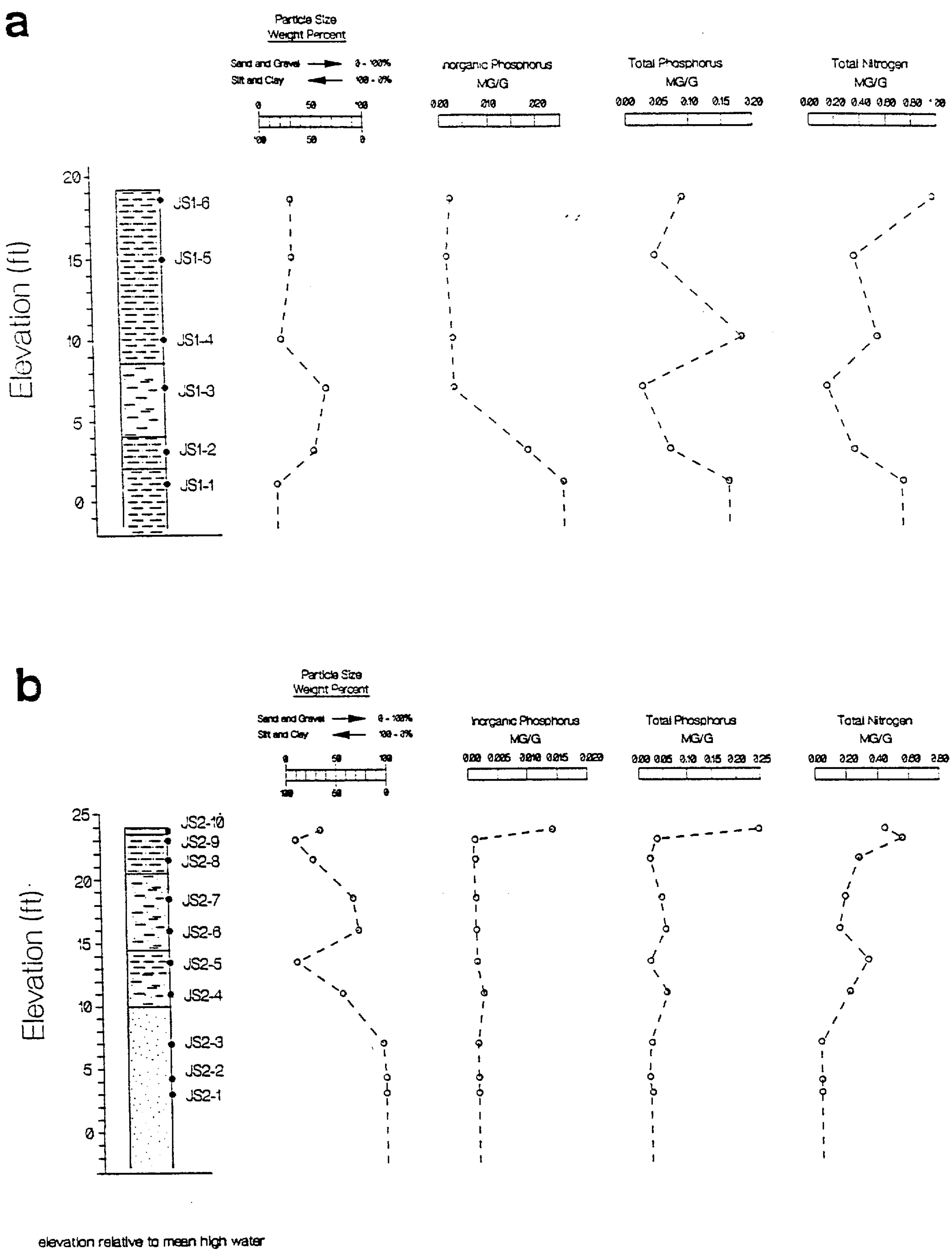


Figure 20. Grain Size, Inorganic Phosphorus, Total Phosphorus and Total Nitrogen: a) James South 1 and b) James South 2.

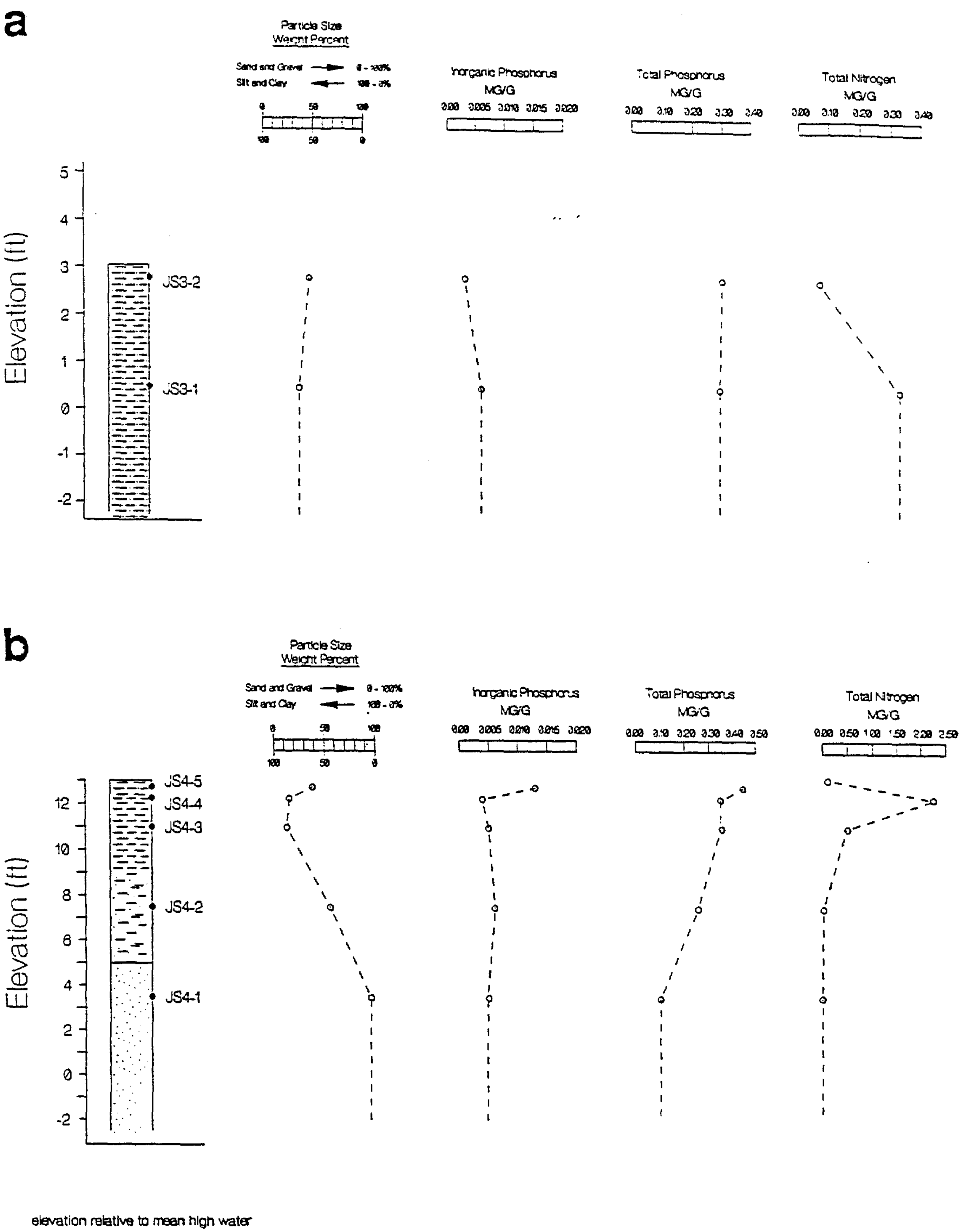
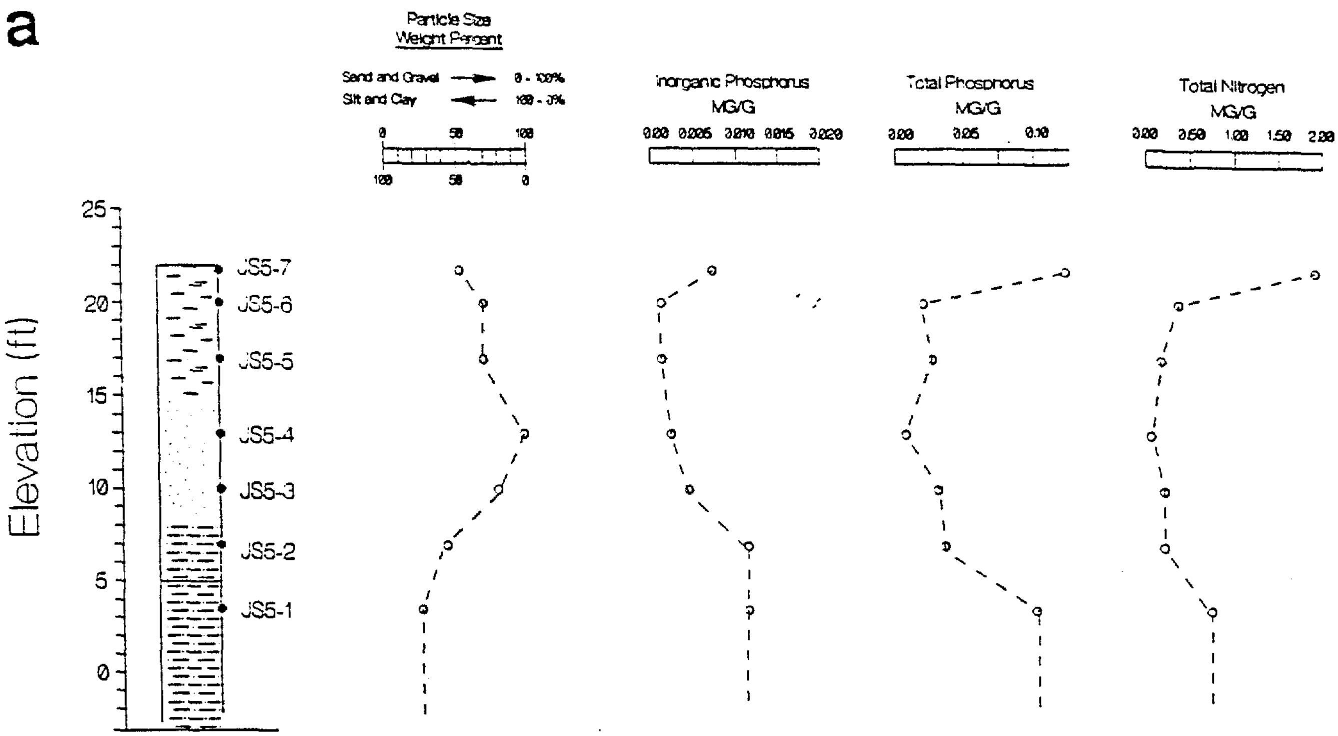


Figure 21. Grain Size, Inorganic Phosphorus, Total Phosphorus and Total Nitrogen: a) James South 3 and b) James South 4.



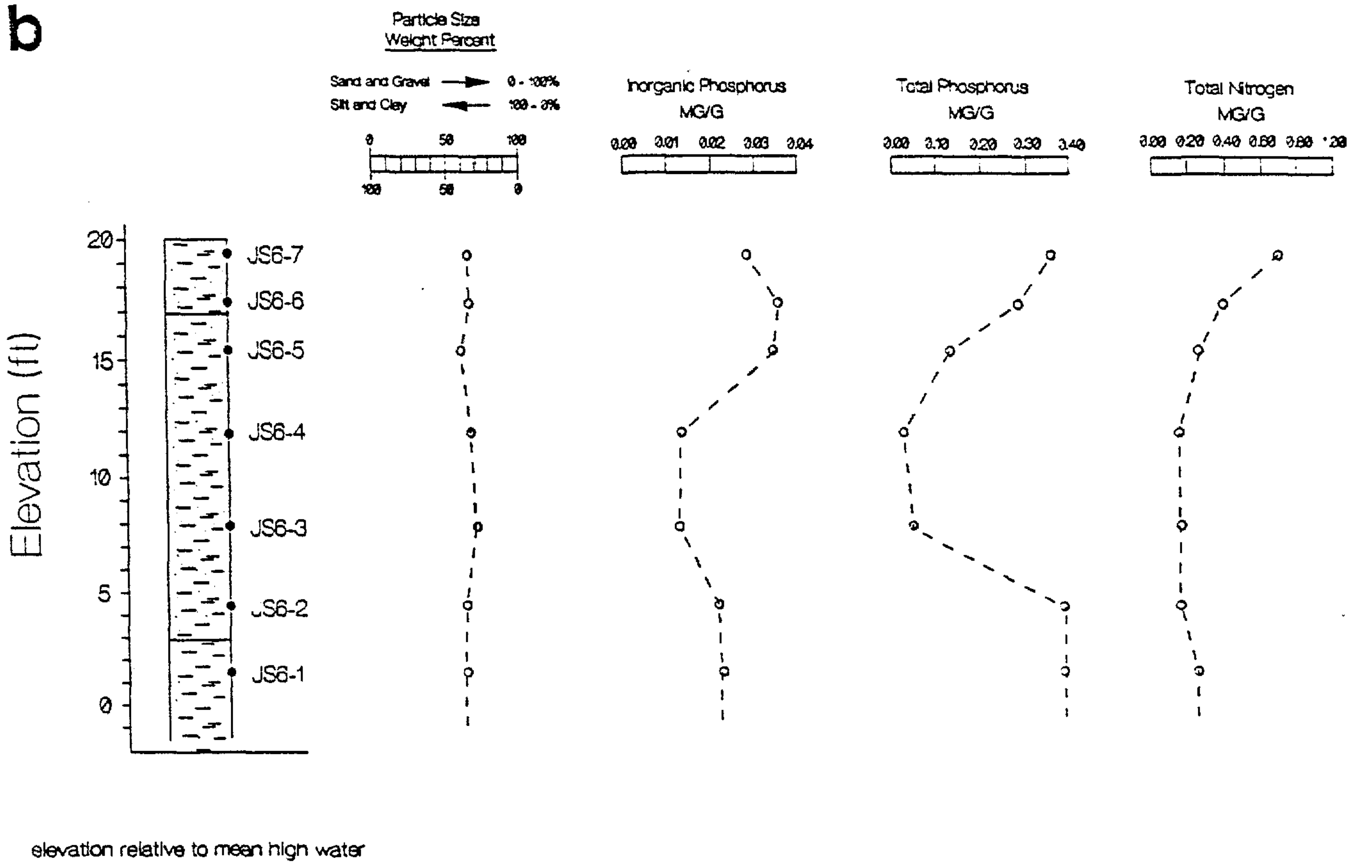


Figure 22. Grain Size, Inorganic Phosphorus, Total Phosphorus and Total Nitrogen: a) James South 5 and b) James South 6.

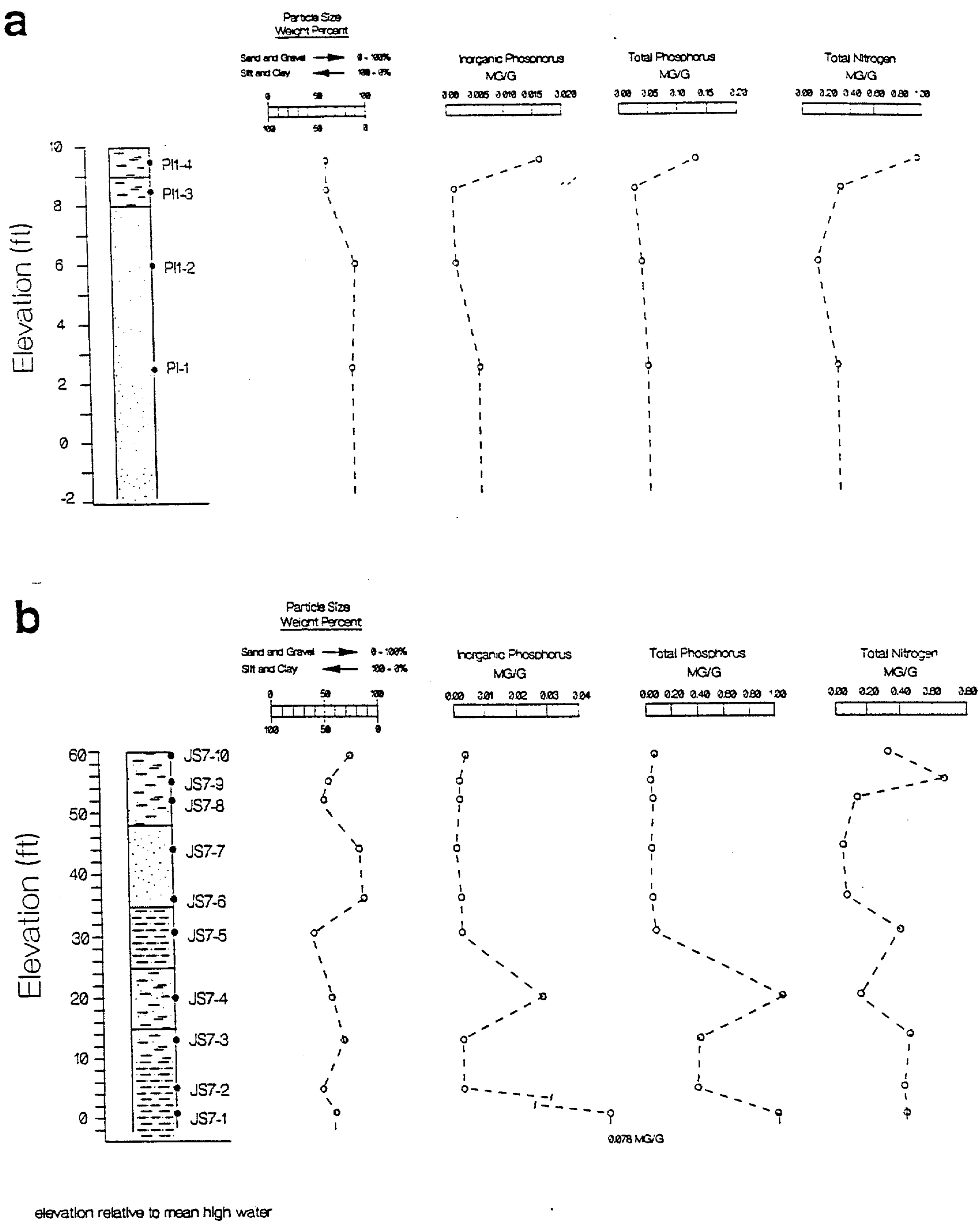


Figure 23. Grain Size, Inorganic Phosphorus, Total Phosphorus and Total Nitrogen: a) James South 7 and b) Piankatank 1.

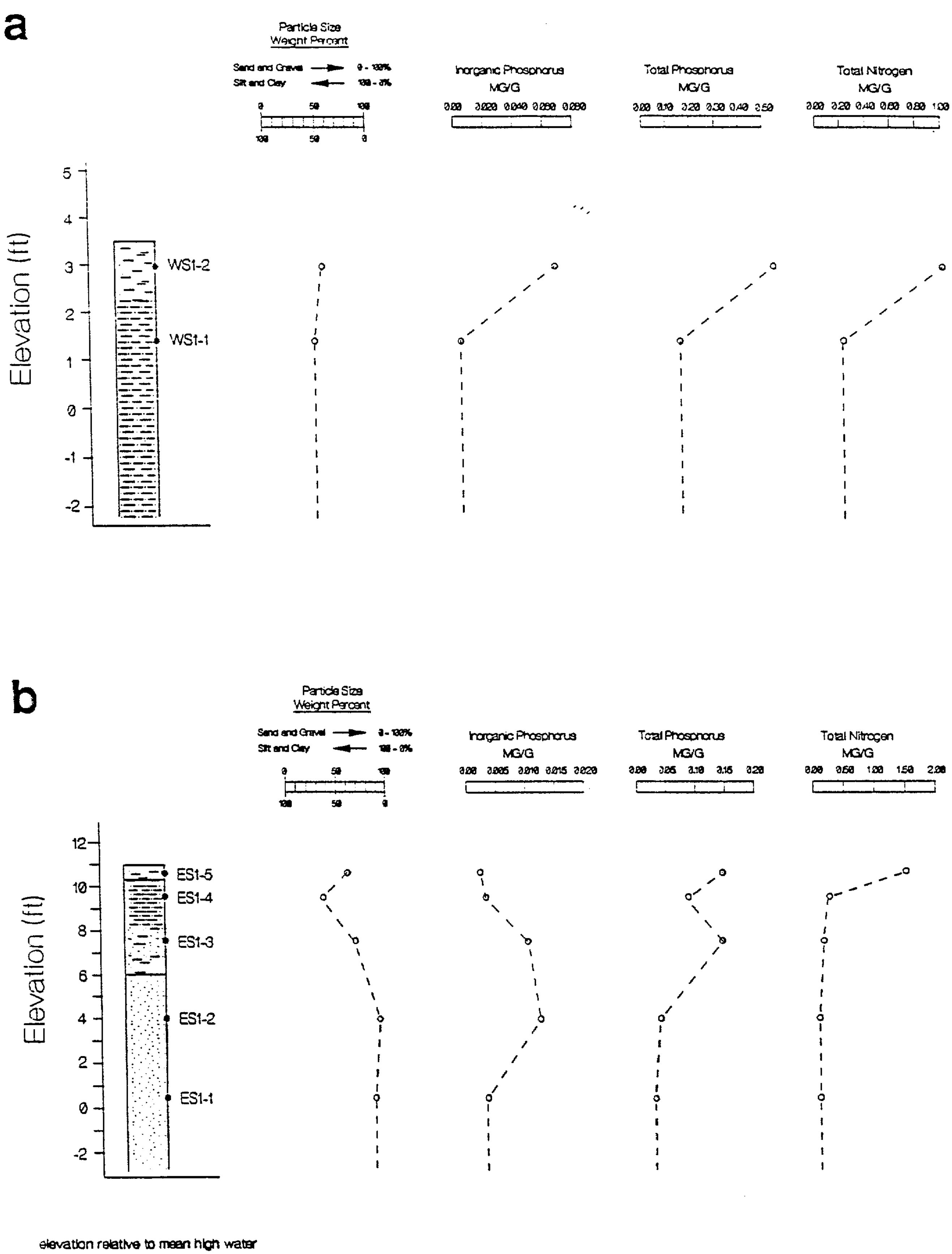


Figure 24. **Grain Size, Inorganic Phosphorus, Total Phosphorus and Total Nitrogen: a) Western Shore 1 and b) Eastern Shore 1.**

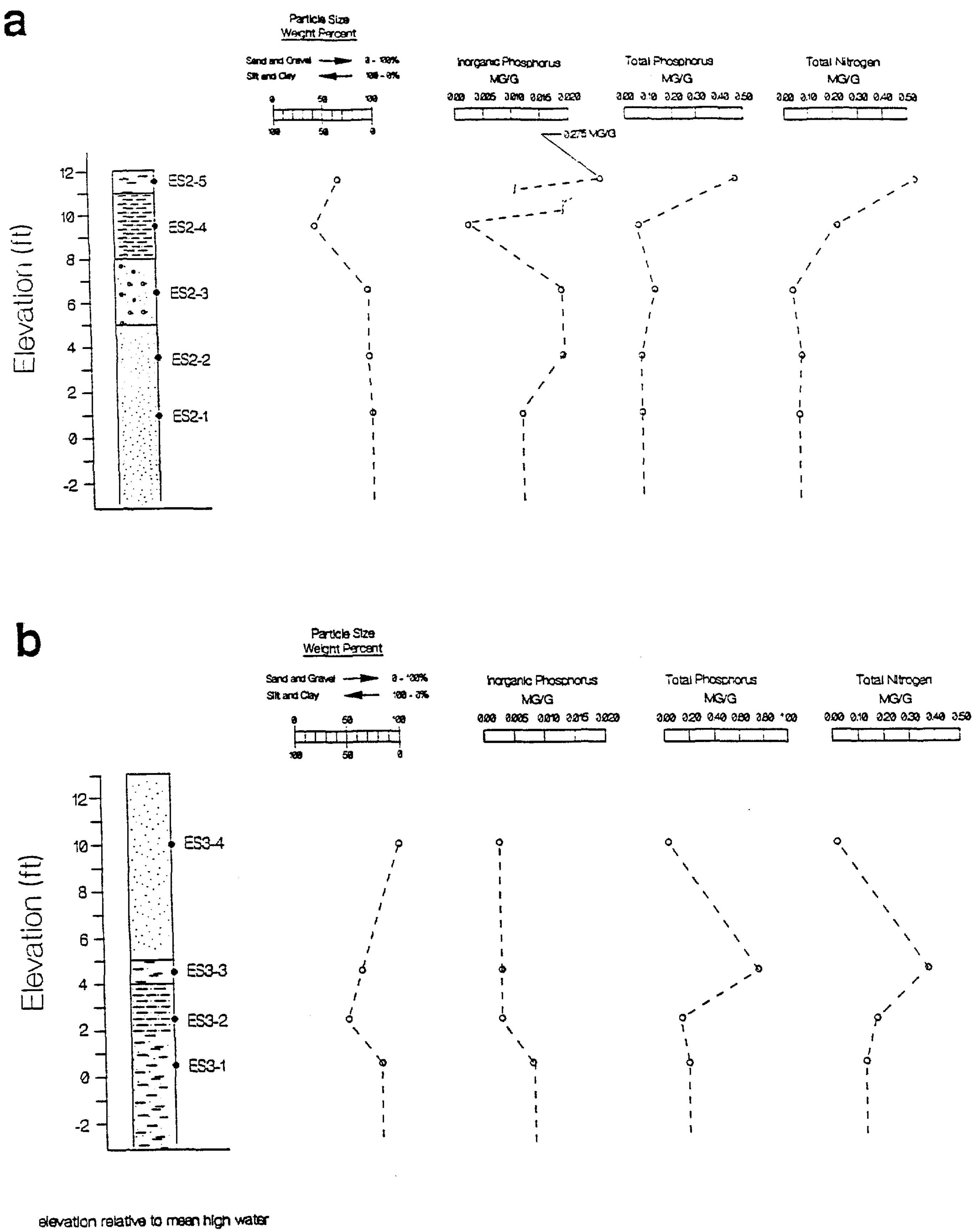


Figure 25. **Grain Size, Inorganic Phosphorus, Total Phosphorus and Total Nitrogen: a) Eastern Shore 2 and b) Eastern Shore 3.**

In Figures 4 through 25, a number of sites with sandy soils showed the "classic trend" of high nutrient concentrations near the surface and decreasing nutrient concentrations with depth. Sites that showed this trend are PS6, RN8, RS3, RS7, JN1, PI1 and ES2. Sandy soils would obviously allow rapid percolation of surface water.

Sites with active groundwater seepage and increased nutrient concentrations in the area of clay layers include PS2, PS3, RN9, RS1, YN2, YN3 and JS5. In contrast, sites RS5, PI1 and ES2 had groundwater seepage but no increase in the nutrient concentrations at depth due to sandy soils throughout the profile. Apparently clay layers collect the nutrients that have leached from upper horizons. A relationship between grain size and total nitrogen had been observed for some sites in the previous research (Ibison et.al., 1990). A relationship between total phosphorus and grain size had been expected because of the bonding capacity of clays for phosphorus. Total nitrogen proved to have a better relationship with grain size than total phosphorus for the sites studied (Ibison et. al., 1990). Simpson (personal communication) noted that nitrate nitrogen is stored in soil micropores. He theorized that the observed nitrogen spikes in the past research may have been influenced by increased micropore volume in fine textured soils.

Although sites RN1, RN3 and YS1 had no evidence of groundwater seepage in the horizons being sampled, favorable precipitation conditions could induce groundwater seepage. At these sites, "spikes" in total nitrogen concentrations were also found to be associated with clay horizons. (At RN3, both total nitrogen and total phosphorus increased in the clay layer in the middle of the bank. It should be noted that groundwater was seeping across a basal clay outcrop below the mean high water elevation. This finding indicates groundwater from different aquifers may be entering the river.)

Nutrient Loading Rates

The mean nutrient loading rates for total nitrogen, total phosphorus and inorganic phosphorus for each site are presented in Tables 2 through 4. Note the high standard deviations, indicating that the loading rates are variable. This finding is not surprising since the nutrient loading concentrations, bank heights and erosion rates used to calculate loading rates vary considerably among the sites. The mean nutrient loading rates and standard deviations for the 14 sites examined in the previous study are presented in Table 5. The mean nutrient loading rates from the previous study were approximately twice those calculated in this study. The previous study focused on reaches with erosion rates greater than 2.0 ft/yr

Table 2. Total Nitrogen Loading Rate Summary

Bank Sample Name	Sediment Loss ton/ft-yr	TN lb/ft-yr	TN lb/ton	TN lb/ac-yr
PS1	2.95	2.93	0.99	36465.9
PS2	2.23	1.09	0.49	16957.3
PS3	3.05	2.16	0.71	22402.3
PS4	0.75	0.66	0.88	14374.8
PS5	1.51	0.82	0.54	9399.8
PS6	2.74	1.20	0.44	10722.5
PS7	1.83	0.79	0.43	7022.9
RN1	0.13	0.12	0.92	13068.0
RN2	0.70	0.34	0.48	21157.7
RN3	0.85	0.67	0.79	41693.1
RN4	1.22	0.87	0.71	14575.8
RN5	1.80	0.79	0.44	14338.5
RN6	0.67	0.14	0.21	3388.0
RN8	0.59	0.26	0.44	6292.0
RN9	1.57	0.38	0.24	23646.9
RS1	1.87	0.52	0.28	14157.0
RS2	2.67	0.96	0.36	22009.3
RS3	0.10	0.67	6.82	138977.1
RS4	4.02	5.88	1.46	77616.0
RS5	0.52	0.10	0.19	6222.9
RS6	0.84	0.67	0.80	16214.0
RS7	4.17	0.87	0.21	11484.0
YN1	0.13	0.12	0.92	13068.0
YN2	0.70	0.34	0.48	21157.7
YN3	0.85	0.15	0.18	9334.3
YN4	0.26	0.17	0.65	4628.3
YS1	1.05	0.52	0.50	16179.4
JN1	0.36	0.11	0.31	6845.1
JN2	0.29	0.34	1.19	55842.5
JN3	1.26	1.58	1.25	57354.0
JN4	0.39	0.30	0.76	18668.6
JN5	0.66	0.65	0.99	40448.6

Table 2. Total Nitrogen Loading Rate Summary (Continued)

Bank Sample Name	Sediment Loss ton/ft-yr	TN lb/ft-yr	TN lb/ton	TN lb/ac-yr
JS1	1.07	0.83	0.78	30129.0
JS2	2.13	0.64	0.30	14672.8
JS3	0.39	0.22	0.56	3422.6
JS4	0.85	0.43	0.50	13379.1
JS5	0.72	0.45	0.62	28002.9
JS6	3.56	1.65	0.46	18914.2
JS7	1.97	1.05	0.53	65340.0
PI1	1.73	0.95	0.55	11184.3
WS1	1.16	1.04	0.89	6380.6
ES1	0.88	0.33	0.38	8455.8
ES2	3.20	0.77	0.24	5884.4
ES3	1.40	0.21	0.15	3977.2
Mean	1.40	0.81	0.73	22624.0
Std. Dev.	1.07	0.95	0.98	24467.2

Table 3. Total Phosphorus Loading Rate Summary

Bank Sample Name	Sediment Loss ton/ft-yr	TP lb/ft-yr	TP lb/ton	TP lb/ac-yr
PS1	2.95	8.87	3.01	110393.5
PS2	2.23	0.53	0.24	8245.3
PS3	3.05	0.60	0.20	6222.9
PS4	0.75	0.11	0.15	2395.8
PS5	1.51	1.73	1.14	19831.3
PS6	2.74	0.08	0.03	714.8
PS7	1.83	0.28	0.15	2489.1
RN1	0.13	0.05	0.38	5445.0
RN2	0.70	0.19	0.27	11823.4
RN3	0.85	0.11	0.13	6845.1
RN4	1.22	0.75	0.62	12565.4
RN5	1.80	0.12	0.07	2178.0
RN6	0.67	0.14	0.21	3388.0
RN8	0.59	0.19	0.32	4598.0
RN9	1.57	0.10	0.06	6222.9
RS1	1.87	0.09	0.05	2450.3
RS2	2.67	2.93	1.10	67174.1
RS3	0.10	0.39	3.97	80897.1
RS4	4.02	2.47	0.62	32604.0
RS5	0.52	0.09	0.17	5600.6
RS6	0.84	0.34	0.40	8228.0
RS7	4.17	0.45	0.11	5940.0
YN1	0.13	0.05	0.38	5445.0
YN2	0.70	0.19	0.27	11823.4
YN3	0.85	0.11	0.13	6845.1
YN4	0.26	0.09	0.34	2450.3
YS1	1.05	1.00	0.95	31114.3
JN1	0.36	0.11	0.31	6845.1
JN2	0.29	0.12	0.42	19709.1
JN3	1.26	0.13	0.10	4719.0
JN4	0.39	0.35	0.89	21780.0
JN5	0.66	0.30	0.46	18668.6

Table 3. Total Phosphorus Loading Rate Summary (Continued)

Bank Sample Name	Sediment Loss ton/ft-yr	TP lb/ft-yr	TP lb/ton	TP lb/ac-yr
JS1	1.07	0.20	0.19	7260.0
JS2	2.13	0.14	0.07	3209.7
JS3	0.39	0.22	0.56	3422.6
JS4	0.85	0.38	0.45	11823.4
JS5	0.72	0.06	0.08	3733.7
JS6	3.56	1.43	0.40	16392.3
JS7	1.97	1.53	0.78	95209.7
PI1	1.73	0.16	0.09	1883.7
WS1	1.16	0.60	0.52	3681.1
ES1	0.88	0.13	0.15	3331.1
ES2	3.20	0.65	0.20	4967.4
ES3	1.40	0.26	0.19	4924.2
Mean	1.40	0.66	0.48	15806.6
Std. Dev.	1.07	1.40	0.72	24553.4

Table 4. Inorganic Phosphorus Loading Rate Summary

Bank Sample Name	Sediment Loss ton/ft-yr	IP lb/ft-yr	IP lb/ton	IP lb/ac-yr
PS1	2.95	3.512	1.19	43709.35
PS2	2.23	0.048	0.02	746.74
PS3	3.05	0.129	0.04	1337.91
PS4	0.75	0.015	0.02	326.70
PS5	1.51	0.044	0.03	504.38
PS6	2.74	0.005	0.00	44.68
PS7	1.83	0.013	0.01	115.57
RN1	0.13	0.001	0.01	108.90
RN2	0.70	0.004	0.01	248.91
RN3	0.85	0.002	0.00	124.46
RN4	1.22	0.025	0.02	418.85
RN5	1.80	0.013	0.01	235.95
RN6	0.67	0.005	0.01	121.00
RN8	0.59	0.005	0.01	121.00
RN9	1.57	0.013	0.01	808.97
RS1	1.87	0.009	0.00	245.03
RS2	2.67	0.486	0.18	11142.19
RS3	0.10	0.101	1.03	20950.29
RS4	4.02	0.372	0.09	4910.40
RS5	0.52	0.006	0.01	373.37
RS6	0.84	0.072	0.09	1742.40
RS7	4.17	0.065	0.02	858.00
YN1	0.13	0.001	0.01	108.90
YN2	0.70	0.004	0.01	248.91
YN3	0.85	0.002	0.00	124.46
YN4	0.26	0.001	0.00	27.23
YS1	1.05	0.050	0.05	1555.71
JN1	0.36	0.003	0.01	186.69
JN2	0.29	0.003	0.01	492.73
JN3	1.26	0.007	0.01	254.10
JN4	0.39	0.011	0.03	684.51
JN5	0.66	0.010	0.02	622.29

Table 4. Inorganic Phosphorus Loading Rate Summary (Continued)

Bank Sample Name	Sediment Loss ton/ft-yr	IP lb/ft-yr	IP lb/ton	IP lb/ac-yr
JS1	1.07	0.012	0.01	435.60
JS2	2.13	0.006	0.00	137.56
JS3	0.39	0.004	0.01	62.23
JS4	0.85	0.010	0.01	311.14
JS5	0.72	0.008	0.01	497.83
JS6	3.56	0.152	0.04	1742.40
JS7	1.97	0.052	0.03	3235.89
PI1	1.73	0.014	0.01	164.82
WS1	1.16	0.049	0.04	300.63
ES1	0.88	0.014	0.02	358.73
ES2	3.20	0.217	0.07	1658.34
ES3	1.40	0.007	0.01	132.57
Mean	1.40	0.127	0.07	2330.4
Std. Dev.	1.07	0.525	0.23	7209.9

Table 5. Nutrient Loading Summary
(Ibison et.al., 1990)

Site	Sediment Loss ton/ft-yr	Loading Rate		Load. Concent.	
		TP lb/ft-yr	TN lb/ft-yr	TP lb/ton	TN lb/ton
Nomini Cliffs	4.75	4.16	5.30	0.88	1.12
Great Point	1.19	0.04	0.52	0.04	0.44
Chesapeake Beach	1.64	0.22	0.79	0.13	0.49
Fleets Island	0.85	0.25	1.49	0.30	1.77
Wellford	1.97	0.22	0.49	0.12	0.25
Canoe House Landing	10.96	1.16	6.44	0.11	0.59
Rosegill	2.45	0.55	0.14	0.23	0.06
Bushy Park Creek	5.26	0.86	0.68	0.16	0.13
Sycamore Landing	3.37	0.84	0.64	0.25	0.19
Pipsico Camp	4.53	2.59	1.14	0.58	0.25
Chippokes State Park	2.14	1.45	1.13	0.69	0.53
Mogarts Beach	4.42	4.42	1.78	1.02	0.41
Silver Beach	3.10	0.40	1.23	0.13	0.40
Tankards Beach	2.39	0.66	1.30	0.28	0.55
Mean	3.50	1.27	1.65	0.35	0.51
Std. Dev.	2.46	1.38	1.79	0.30	0.43

and erosion volumes greater than 1.0 $yd^3/ft/yr$. The sites in the present study were selected to obtain a wide range of soil stratigraphies to provide more complete coverage of the lower Chesapeake Bay estuarine system. In general, the reaches sampled had lower erosion rates and eroded soil volumes than the sites from the previous research. Therefore, the present study reflects the lower nutrient loading rates.

The variability in nutrient loading rates for each river system and the Bay is clearly depicted in Figures 26 through 35. The inorganic phosphorus loading rates are graphed separately from total nitrogen and total phosphorus due to differences in scale. In many instances, the inorganic phosphorus loading rate was only slightly higher than the detection limit. Although readily available (inorganic) phosphorus loading was minimal, phosphorus measured as total phosphorus could become available under favorable conditions.

The sites with total nitrogen loading rates greater than or equal to 1 lb/ft-yr were PS1, PS2, PS3, PS6, RS4, JN3, JS6, JS7 and WS1. These sites were located throughout the Bay system and not confined to a particular river. The sites with total phosphorus loading rates greater than or equal to 1 lb/ft-yr were PS1, PS5, RS2, RS4, YS1, JS6, and JS7.

Nutrient Loading Concentrations

The nutrient loading concentrations for total nitrogen, total phosphorus and inorganic phosphorus are also presented in Tables 2 through 4. The mean nutrient loading concentrations were used in Ibison et. al. (1990) to estimate the total quantity of nitrogen and phosphorus entering the lower Chesapeake Bay estuarine system from shoreline erosion. The mean total nitrogen and total phosphorus loading concentrations in this study were 0.73 lb/ton and 0.48 lb/ton, respectively. In the previous research, the means for total nitrogen and total phosphorus were 0.51 lb/ton and 0.35 lb/ton, respectively (Table 5). The nutrient loading concentrations are of the same order of magnitude and similar in value. In all instances, the standard deviations were high.

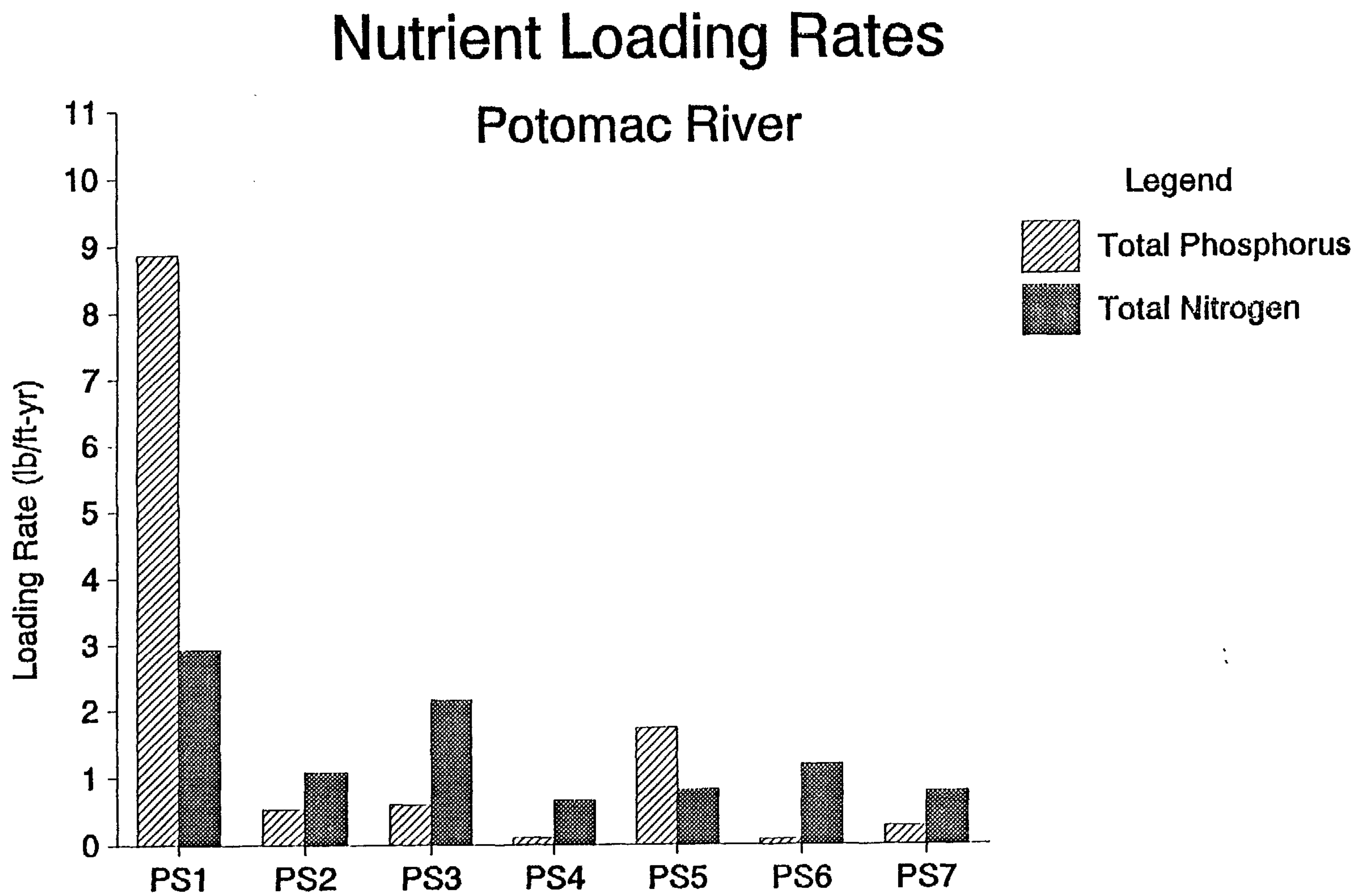


Figure 26. Nutrient Loading Rates - Potomac River, Total Phosphorus and Total Nityrogen

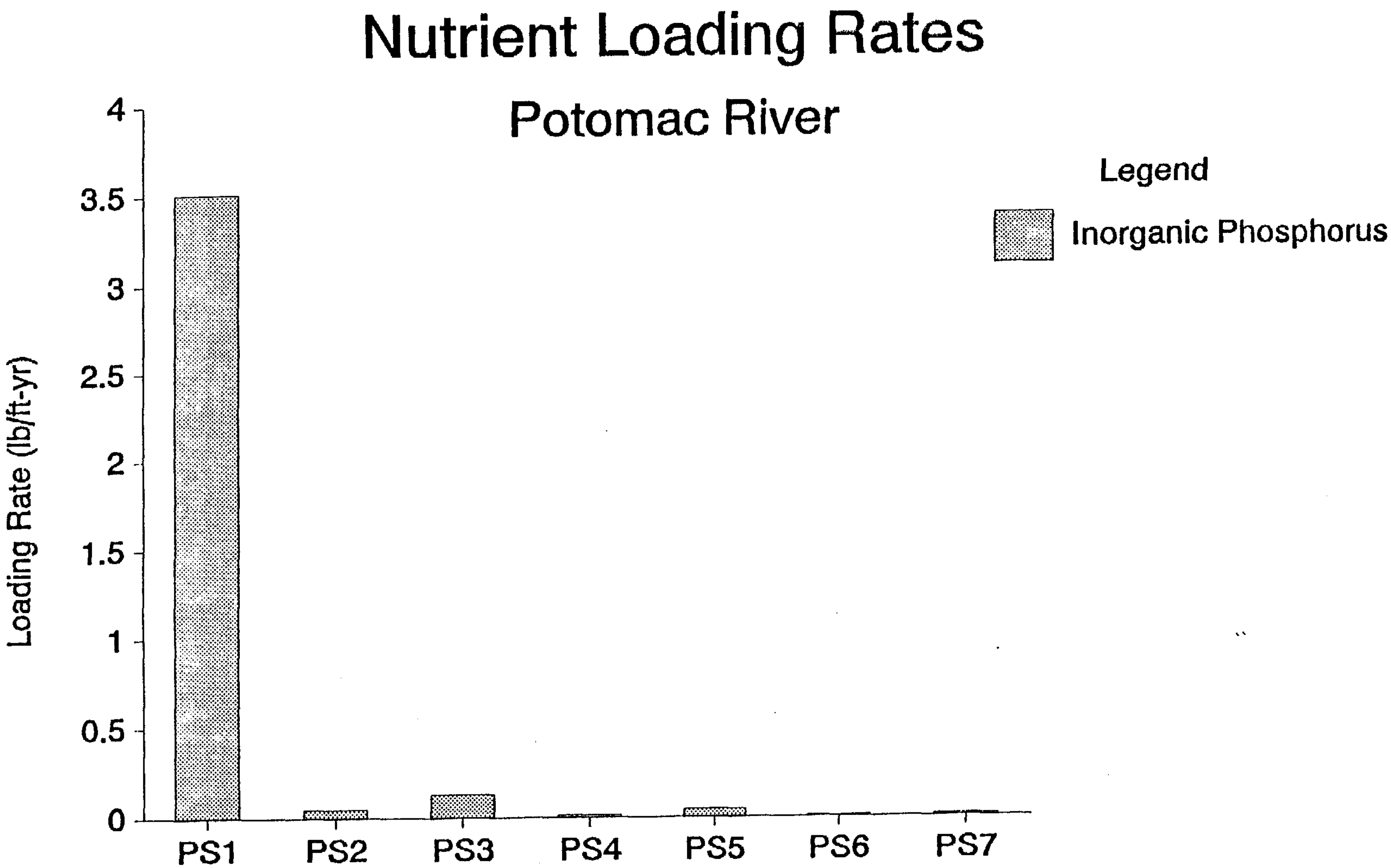


Figure 27. Nutrient Loading Rates - Potomac River, Inorganic Phosphorus

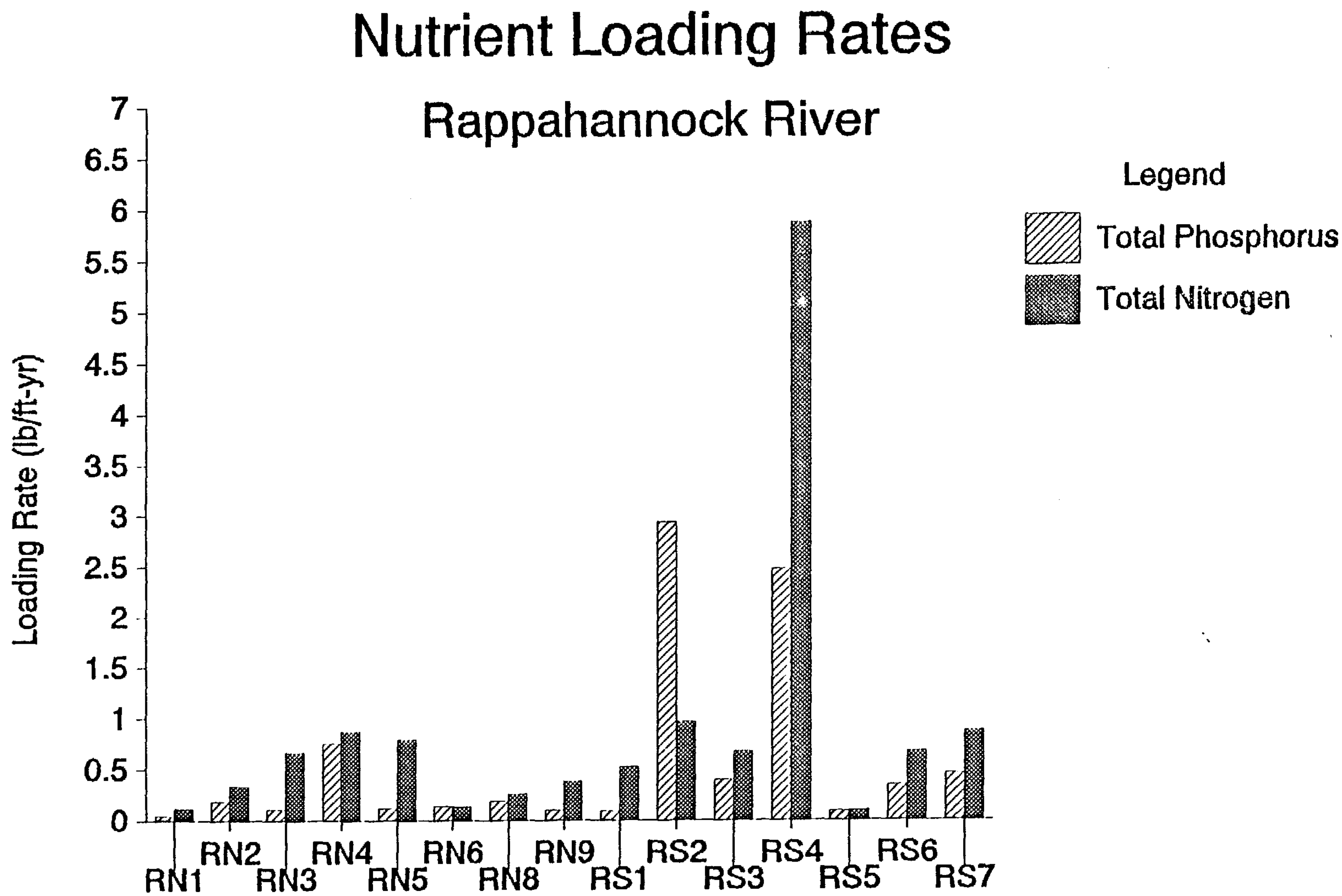


Figure 28. Nutrient Loading Rates - Rappahannock River, Total Phosphorus and Total Nitrogen

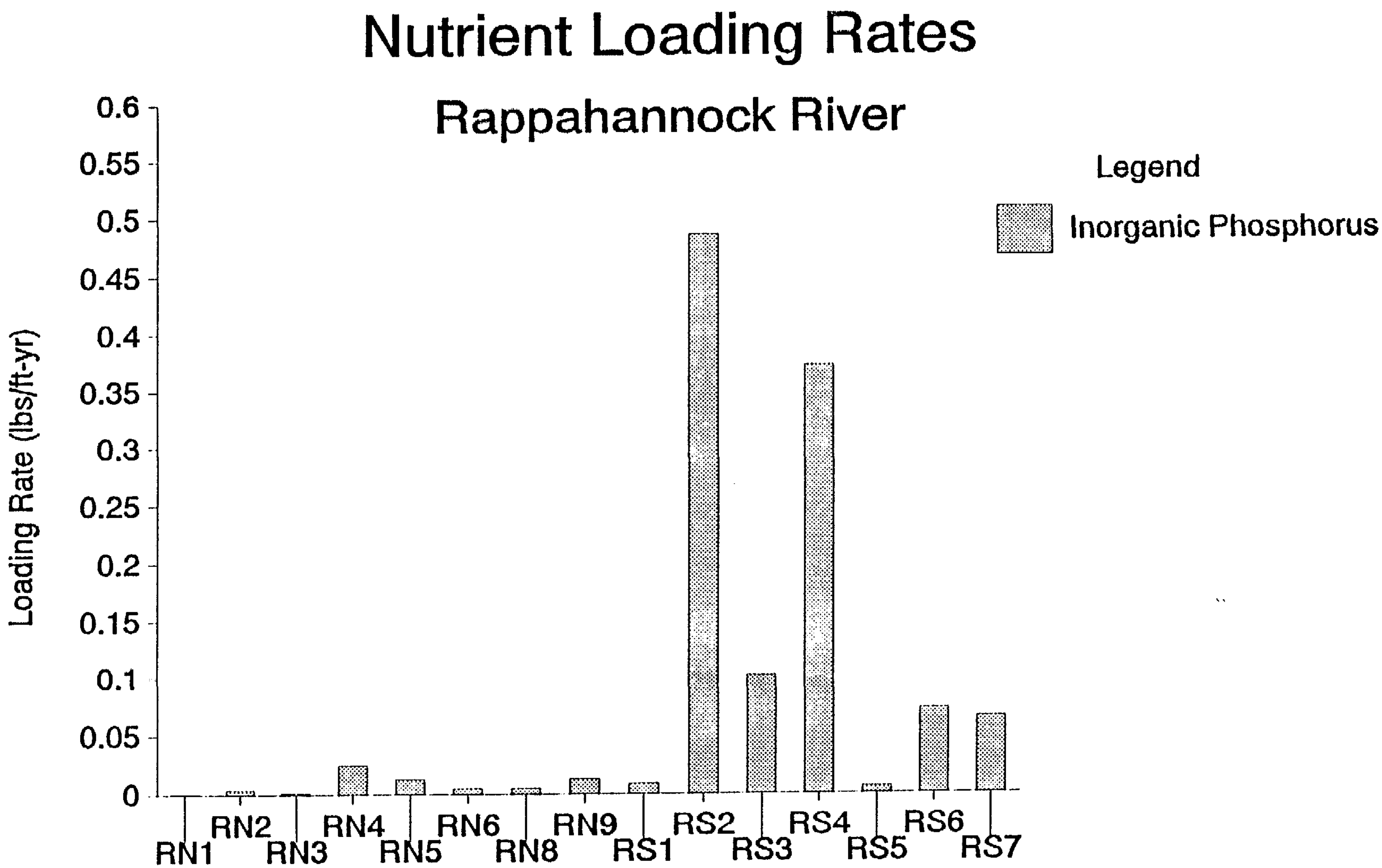


Figure 29. Nutrient Loading Rates - Rappahanock River, Inorganic Phosphorus

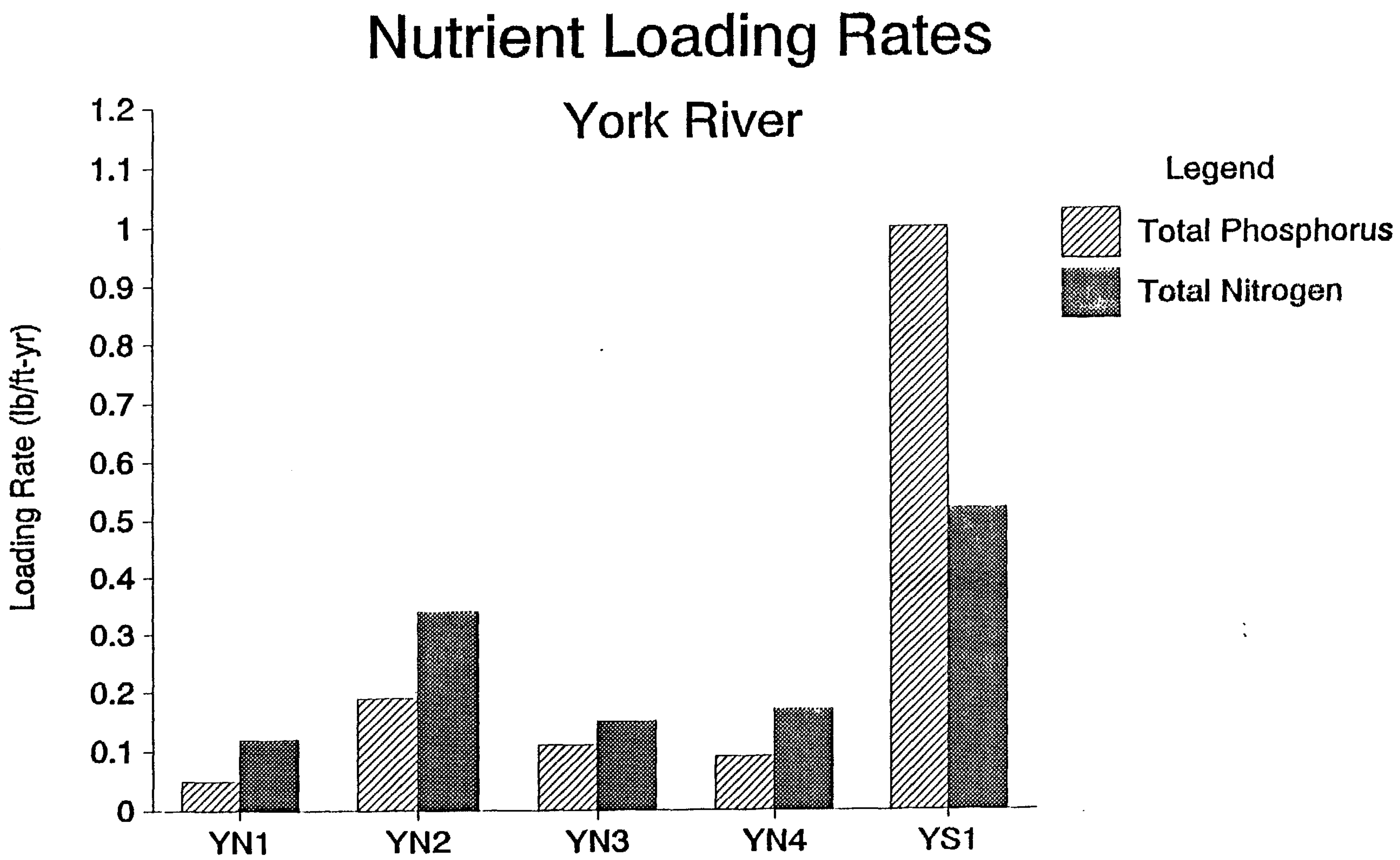


Figure 30. Nutrient Loading Rates - York River, Total Phosphorus and Total Nitrogen

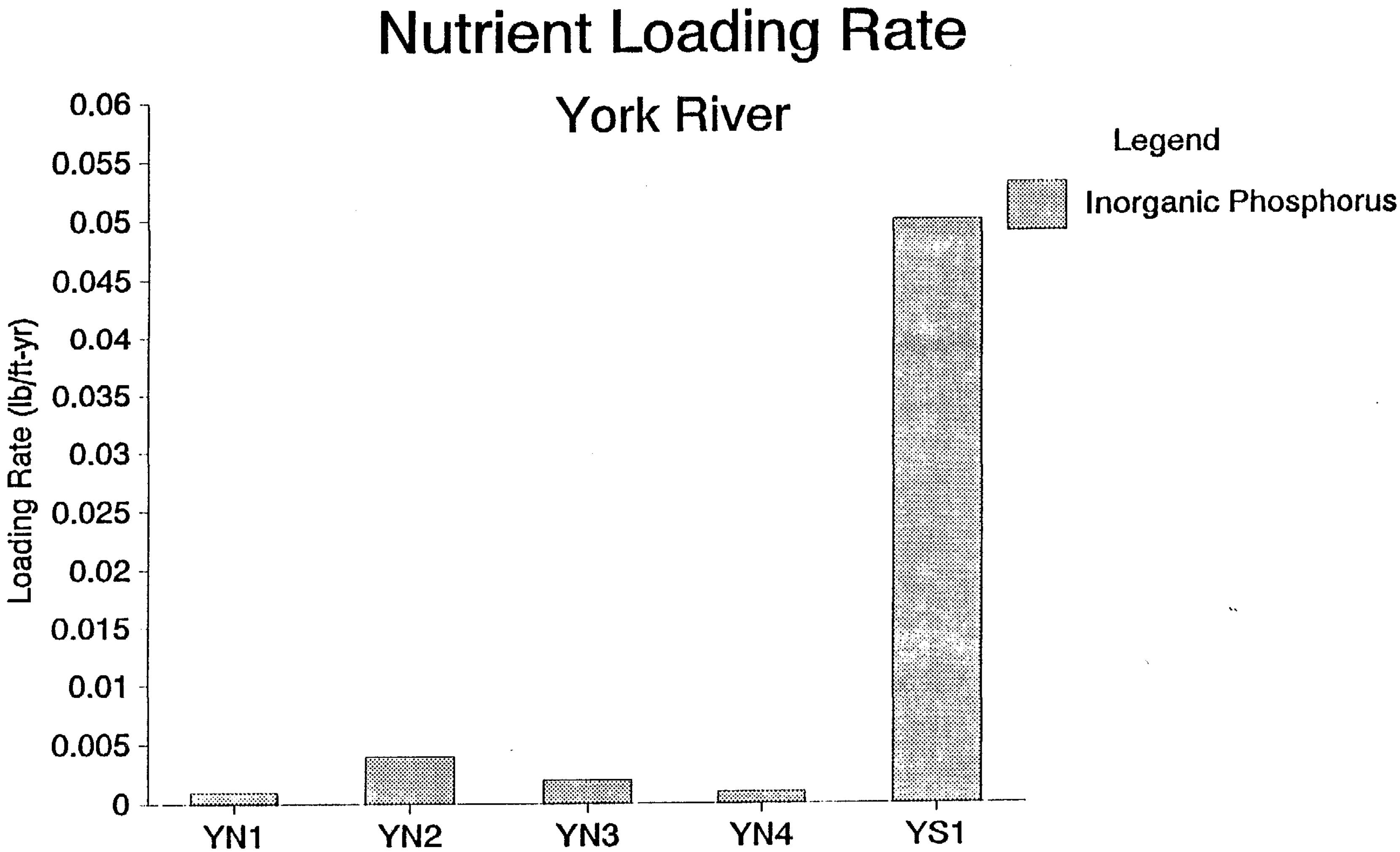


Figure 31. Nutrient Loading Rates - York River, Inorganic Phosphorus

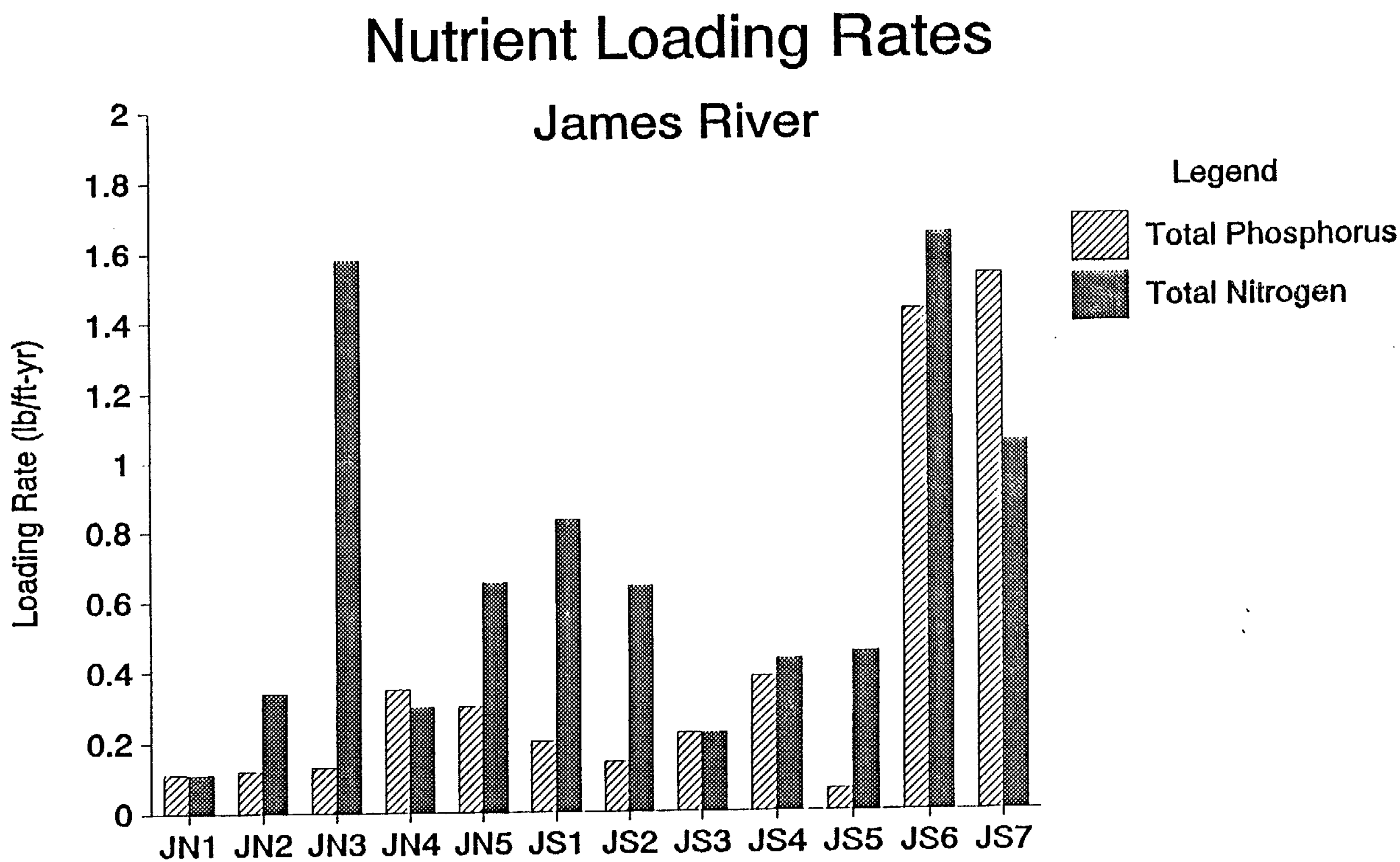


Figure 32. Nutrient Loading Rates - James, Total Phosphorus and Total Nitrogen

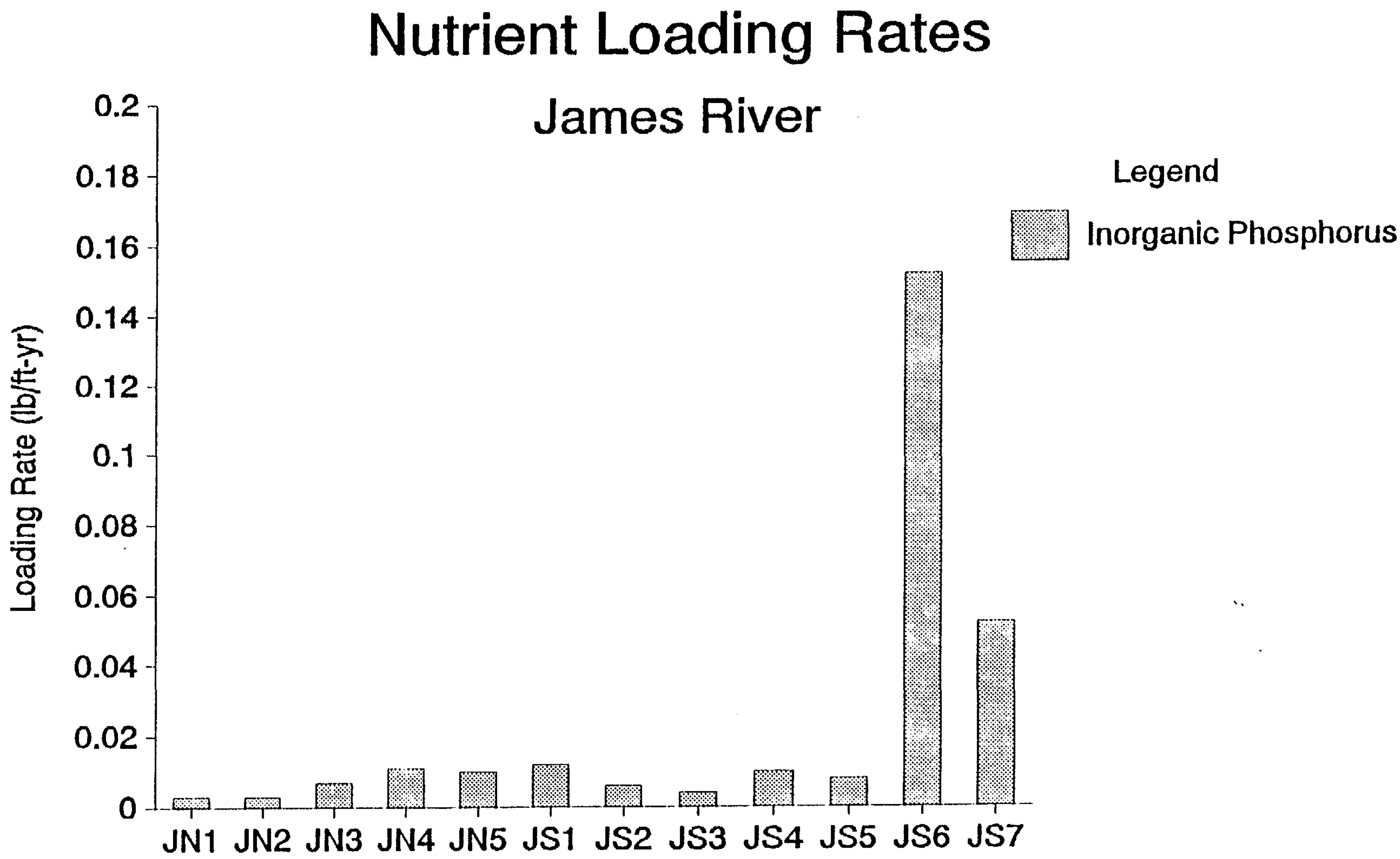


Figure 33. Nutrient Loading Rates - James River, Inorganic Phosphorus

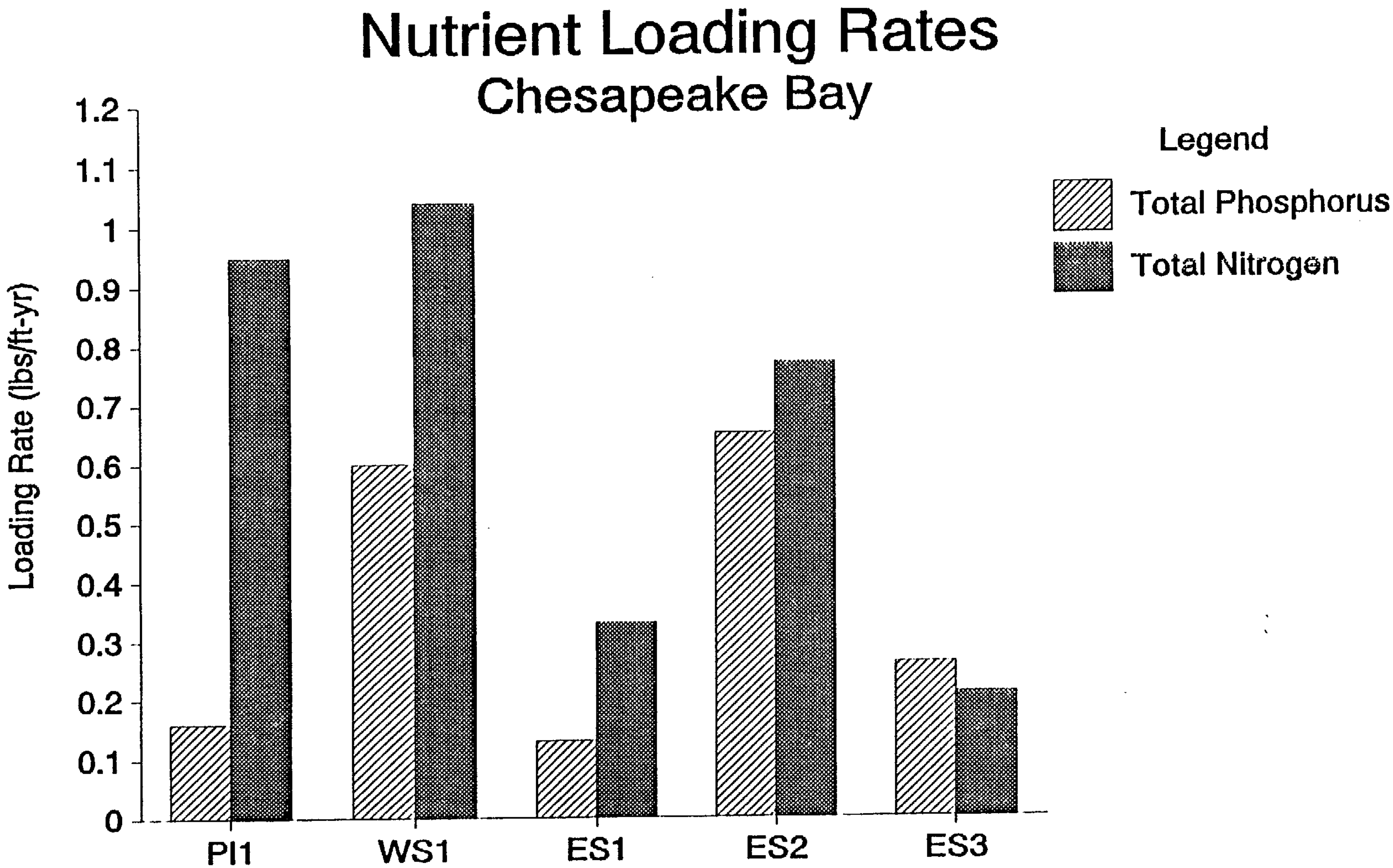


Figure 34. Nutrient Loading Rates - Chesapeake Bay, Total Phosphorus and Total Nitrogen

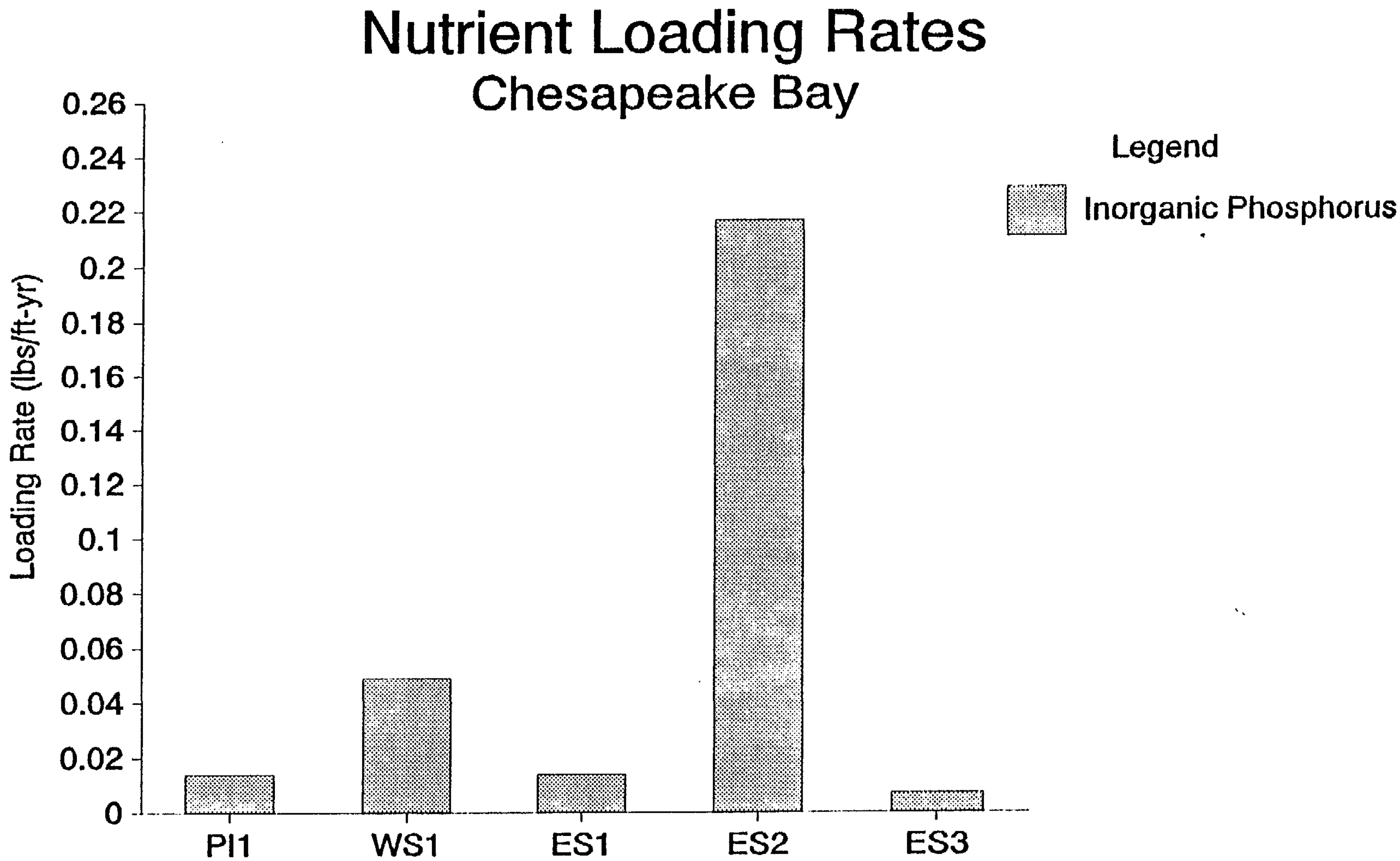


Figure 35. Nutrient Loading Rates - Chesapeake Bay, Inorganic Phosphours

Phosphorus Concentrations in Banks with Fossiliferous Horizons

Six sites had fossiliferous layers in their stratigraphy. These sites are: PS5, RS2, RS4, YN2, JS6 and JS7. The sites occurred in all 4 major tributaries. However, they only represent 14% of the sites sampled.

For the sites with fossiliferous layers, the mean loading concentration for inorganic phosphorus was 0.06 lb/ton and total phosphorus was 0.72 lbs/ton. The standard deviations were 0.06 and 0.33, respectively. For the 38 sites without fossil layers, the mean inorganic phosphorus loading concentration was 0.06 lb/ton and total phosphorus was 0.39 lbs/ton. The standard deviations were 0.23 and 0.72, respectively. For inorganic phosphorus, the nutrient loading concentration was the same for both groups. The total phosphorus loading concentration was almost twice as high for the fossiliferous group. The higher total phosphorus loading concentration may be related to the presence of apatite.

Nutrient Loading Concentrations and Landuse

One objective of this study was to determine the effect of landuse on the nutrient concentrations of eroding shoreline banks. The following four landuse types have been identified for the sites studied: active farm, fallow farm, wooded and rural residential. Of the 44 sites studied, 14 were active farms, 8 were fallow farms, 16 were wooded and 6 were rural residential. The landuse types represent 32%, 18%, 36% and 14% respectively of the total number of sites. Table 6 and Figures 36 through 40 show the loading concentrations by landuse type. The mean loading concentration for each landuse type is depicted in Figure 36. Loading concentrations by landuse type are provided in Figures 37 through 40.

The mean total nitrogen and total phosphorus loading concentrations were high for active farmland, as was expected. Surprisingly, the mean total nitrogen loading concentration for wooded land was as high as for active farmland. Of the wooded sites, JN3 had the highest loading concentration, which seems to be related to the very high nitrogen and carbon concentrations found in organic peaty layer at the base of the bank. A similar situation existed for YN2, although the mean nitrogen concentration for the site was not unusually high. The other wooded sites generally had high total nitrogen and carbon concentrations in the topsoil. Some sites had high nitrogen concentrations associated with clay layers.

Table 6. Nutrient Loading Concentrations by Land Use

Active Farm Loading Concentrations		
Site	TP lb/ton	TN lb/ton
PS1	3.02	1.00
PS2	0.24	0.50
PS3	0.20	0.72
PS4	0.14	0.90
RN2	0.86	0.26
RN4	0.62	0.72
RN8	0.32	0.44
RS1	0.04	0.28
RS4	0.62	1.48
RS6	0.40	0.80
JN1	0.32	0.30
JN4	0.90	0.76
JS4	0.44	0.50
JS6	0.40	0.46
Mean	0.61	0.65
Std. Dev.	0.71	0.32

Fallow Farm Loading Concentrations		
Site	TP lb/ton	TN lb/ton
PS5	1.16	0.54
PS7	0.16	0.44
RS2	1.10	0.36
RS3	0.40	0.68
JS7	0.78	0.54
PI1	0.10	0.56
ES2	0.20	0.24
ES3	0.18	0.16
Mean	0.51	0.44
Std. Dev.	0.41	0.16

Wooded Loading Concentrations		
Site	TP (lb/ton)	TN (lb/ton)
PS6	0.02	0.44
RN1	0.14	0.64
RN3	0.06	0.46
RN6	0.20	0.22
YN1	0.36	0.92
YN2	0.26	0.48
YN4	0.24	0.66
YS1	0.96	0.50
JN2	0.16	0.46
JN3	0.10	1.26
JN5	0.46	1.00
JS1	0.18	0.78
JS2	0.06	0.30
JS3	0.58	0.58
JS5	0.08	0.64
ES1	0.52	0.90
Mean	0.27	0.64
Std. Dev.	0.24	0.27

Rural Residential Loading Concentrations		
Site	TP lb/ton	TN lb/ton
RN5	0.06	0.44
RN9	0.06	0.24
RS5	0.16	0.20
RS7	0.10	0.22
YN3	0.12	0.18
WS1	0.52	0.90
Mean	0.17	0.36
Std. Dev.	0.16	0.25

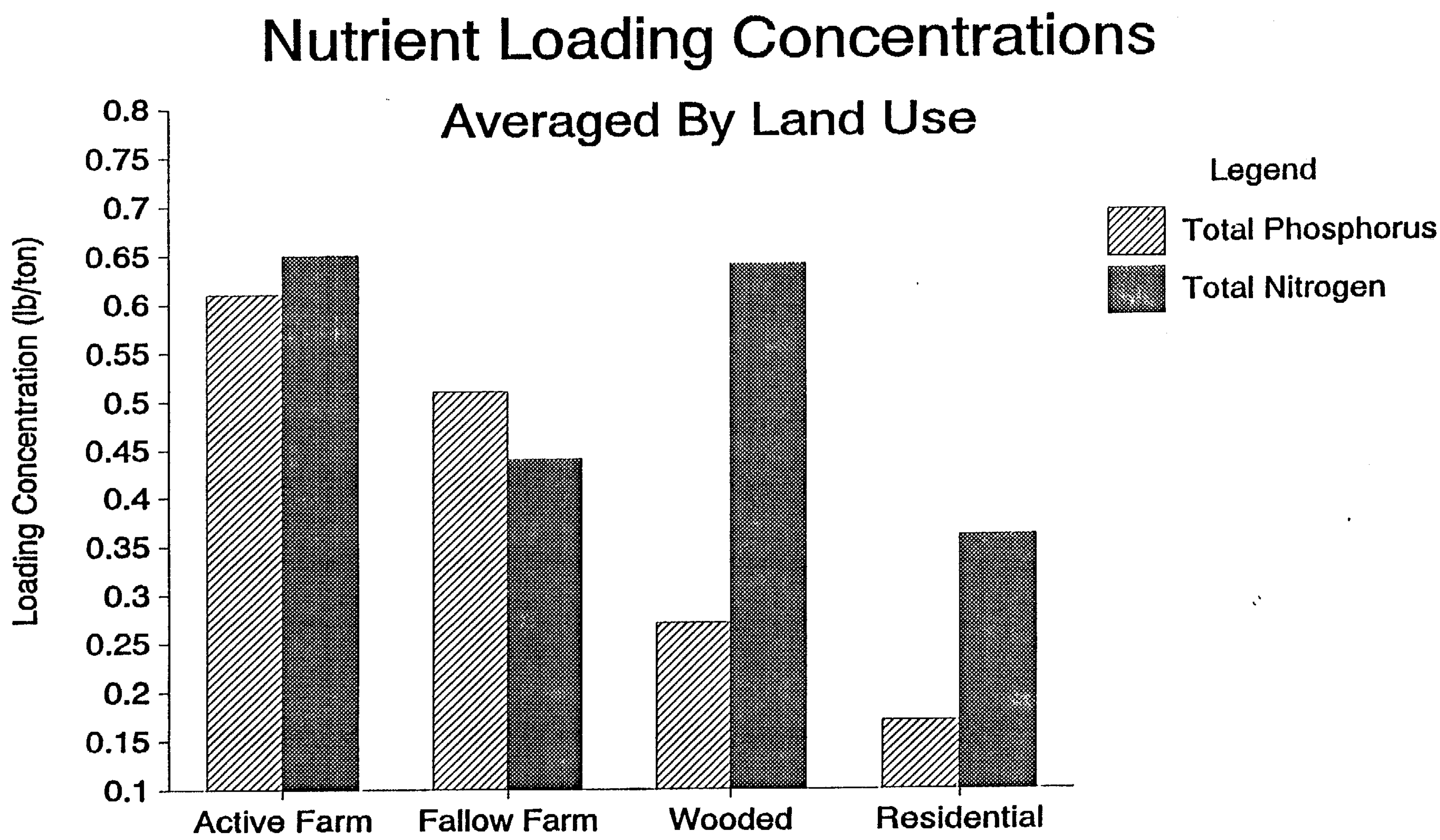


Figure 36. Nutrient Loading Concentrations - Averaged by Landuse

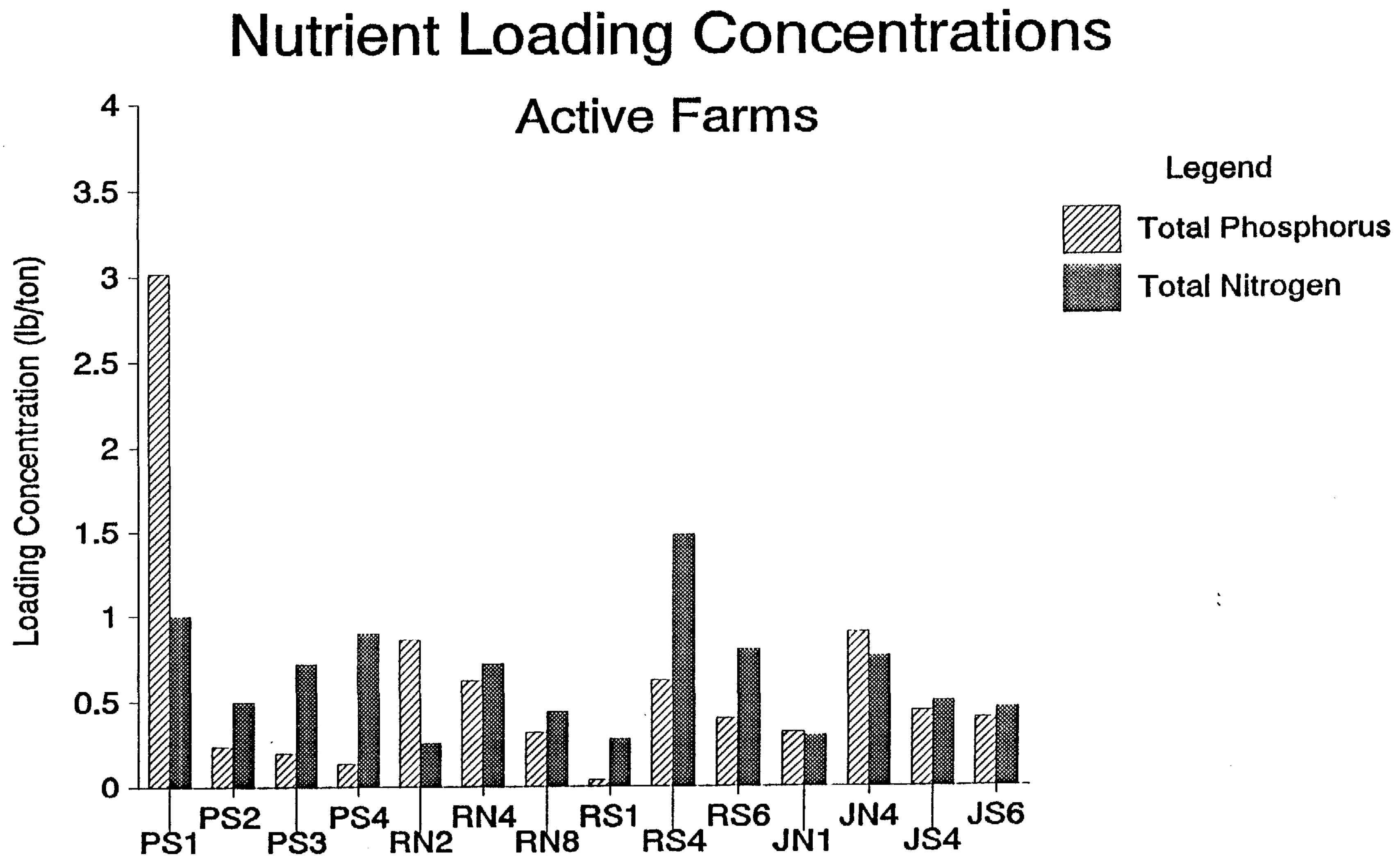


Figure 37. Nutrient Loading Concentrations - Active Farms

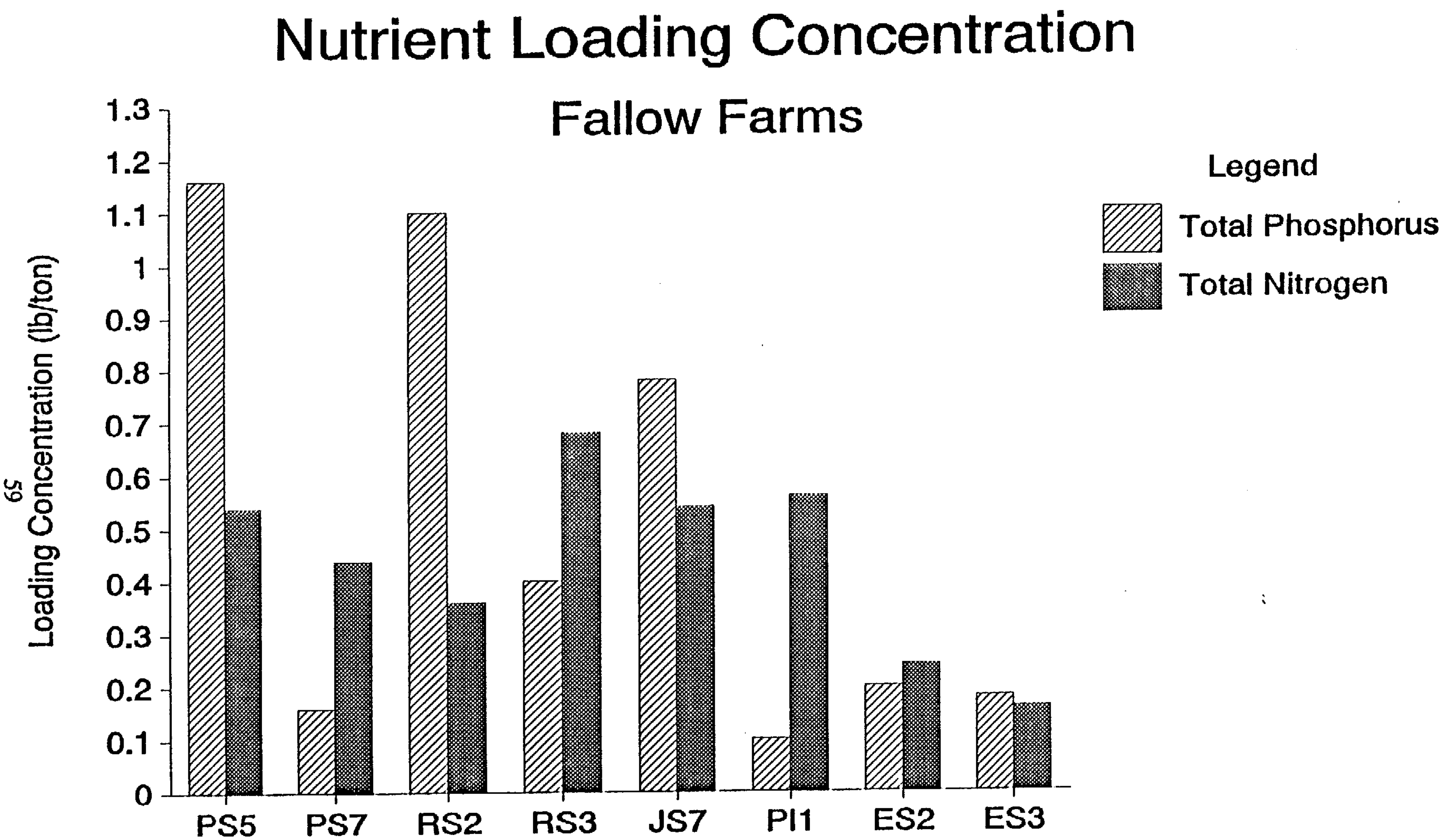


Figure 38. Nutrient Loading Concentrations - Fallow Farms

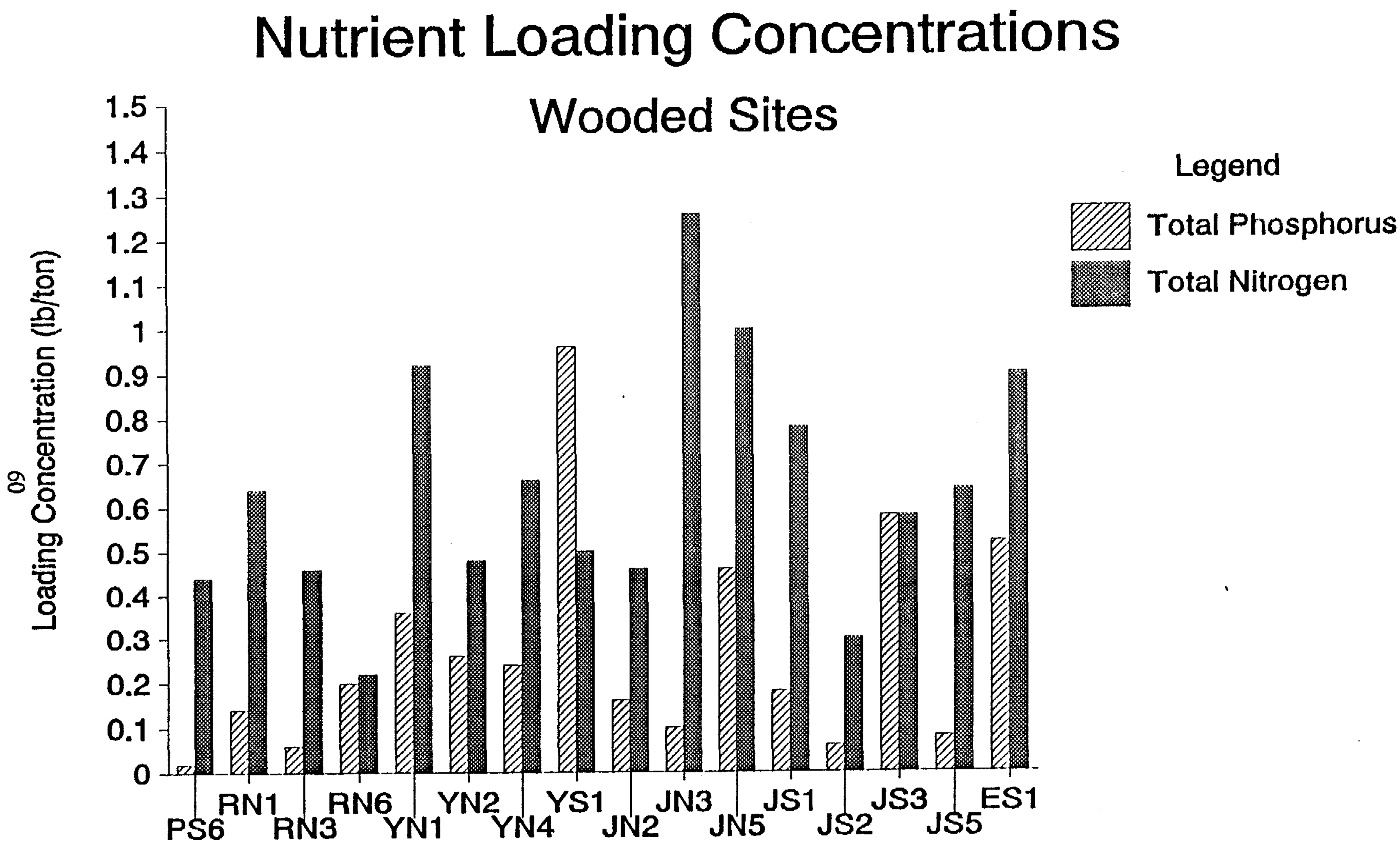


Figure 39. Nutrient Loading Concentrations - Wooded Sites

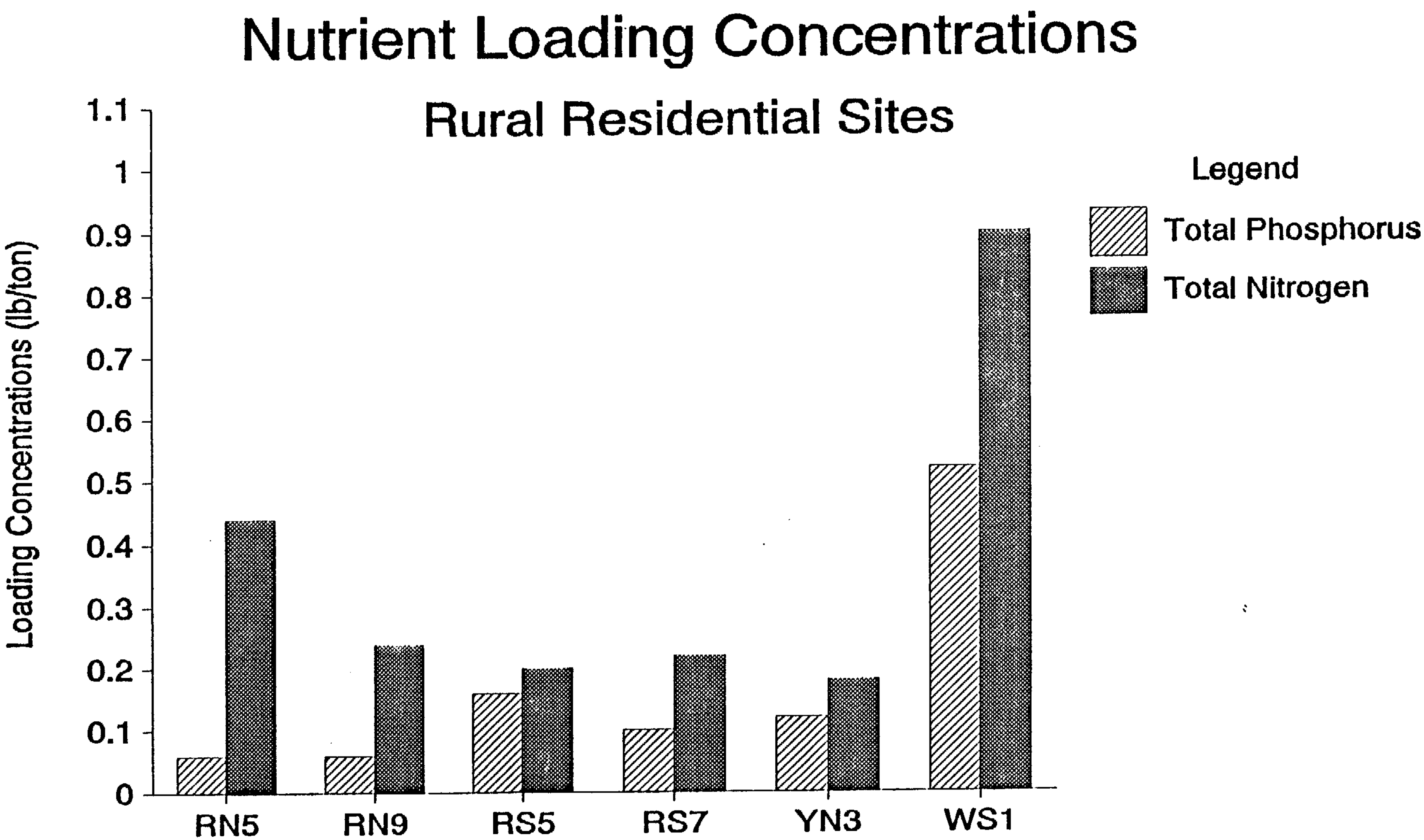


Figure 40. Nutrient Loading Concentrations - Rural Residential Sites

Phosphorus loading concentrations decreased from active farmland to rural residential. Of the six sites with fossiliferous layers, 3 were fallow farms, 2 were wooded and 1 was an active farm. The relatively high mean phosphorus loading concentration for fallow farms appears to be influenced by the three (3) sites with fossils. The remaining fallow farm sites had relatively sandy soils.

V. DISCUSSION

Comparison of Shoreline Erosion with Upland Erosion

The purpose of this study was to verify and expand the results of the previous research by Ibison et. al. (1990). The new research confirmed that nutrient loading concentrations and loading rates are extremely variable from site to site.

The nutrient contributions from shoreline erosion can be compared to upland agricultural erosion using loading concentrations and loading rates. The nutrient loading concentrations are lower for shoreline banks than agricultural runoff, as discussed below. In contrast, the high nutrient loading rates clearly demonstrate the much greater relative impact of shoreline erosion to estuarine water quality.

Nutrient loading concentrations from Virginia's Agricultural BMP Cost-Share program provide a reference with which to compare loading concentrations from shoreline erosion. The effectiveness of agricultural BMPs is assessed using an average total nitrogen loading concentration of 5.44 pounds per ton of soil and total phosphorus concentrations that vary state-wide from 0.68 to 1.88 pounds per ton of soil (Chesapeake Executive Council, 1988). In comparison, the mean total nitrogen and total phosphorus loading concentrations determined in this bank erosion study were much lower, 0.73 and 0.48 pounds per ton of soil, respectively. The loading concentrations used for agricultural BMP assessments reflect nutrient losses to surface waters from the nutrient enriched topsoil layer. The loading concentrations for shoreline banks, in contrast, are weighted for the soil stratigraphy of the entire bank.

The nutrient loading rates reflect the fundamental difference between the nutrient load from upland erosion versus shoreline erosion. The large mass of material lost through shoreline erosion allows tons of soil with associated nutrients to be input directly into the Bay system. Although agricultural land may have higher nutrient loading concentrations, the underlying soil horizons remain relatively undisturbed and do not contribute to downstream nutrient loading. The sheer mass of material lost through shoreline erosion results in nutrient loading rates several orders of magnitude higher than similar upland loading rates. This difference is readily apparent when the nutrient loading rates are converted to lbs/acre-yr and compared to agricultural loading rates for comparable land areas. Beaulac and Reckhow (1982) reported a range of total nitrogen export rates for cultivated farmland from the literature varying from 1.88 to 71.02 lbs/acre/yr (2.1 to 79.6 kg/ha/yr) and total phosphorus export rates varying from 0.23 to 108.81 lbs/acre/yr (0.26 to 18.6 kg/ha/yr). Due to the quantity of soil loss due to shoreline erosion, the comparable loss of nutrients per shoreline acre is 22,624 lbs/acre-yr for total nitrogen and 15,807 lbs/acre-yr for total phosphorus (Tables 2 and 3).

Another notable difference between shoreline erosion and upland erosion involves the proximity of the nutrient input to the water body. In all shoreline erosion cases, nutrient loads are input directly into the water. In addition, the nature of shoreline erosion versus upland erosion is that the former results in the complete loss of land and subsequent unrecoverable loss in real estate tax base. In contrast, upland erosion primarily depletes the topsoil's ability to support agriculture. Shoreline land loss may also damage or destroy shore adjacent BMPs that were installed to minimize upland nonpoint source pollution.

Nutrient Loading Concentrations for Fossiliferous Banks

The mean total phosphorus loading concentration for the 6 banks with fossiliferous horizons was approximately twice that found for the 38 banks without fossil layers. The inorganic phosphorus loading means were the same for both groups. Since the fossiliferous sites represented only 14% of the sites sampled, fossiliferous horizons were not a factor in most of the banks studied. The highest total phosphorus loading concentrations were found at 2 sites with no fossils: PS1, an active farm and RS3, a fallow farm with high nutrient levels in the upper horizon. For the purpose of calculating nutrient loading estimates for the entire Bay, the mean total phosphorus loading concentration for the non-fossiliferous sites could be used to reduce possible errors.

Nutrient Loading Concentrations and Landuse

The landuse comparisons indicated differences among the four landuse types. Active farmland proved to have the highest loading concentrations, as would be expected. The high total nitrogen load found for wooded land was an unexpected result because of research showing nitrogen reduction by wooded riparian buffers (Peterjohn and Correll, 1984; Correll and Weller, 1989; Correll, 1991). The forested buffers studied by Correll and colleagues occurred along sloping banks of first order streams with wetland soils present. Correll and Weller (1989) determined the high rates of nitrogen loss were due to denitrification by the wetland soils beneath the forest. For denitrification to occur, two conditions appear to be necessary: low redox conditions of the soils and large amounts of organic matter (Correll, unpublished lecture). In contrast, the wooded sites examined in the present study occurred on the tops of eroding bluffs where wetland soils were not present. It would appear that without suitable hydrology and soil conditions for denitrification, the effectiveness of forested buffers for nitrogen removal would be limited to nitrogen uptake by the trees and filtration of surface runoff. While forested buffers appear to be very effective in reducing nitrogen in headwater areas with wetland soils, the findings of the present research suggest low nitrogen removal efficiency for the upland forests along *eroding shoreline bluffs* of major rivers and the Bay.

Nutrient Management Implications

To achieve the 40% nonpoint source nutrient reduction goal of the Chesapeake Bay Agreement, management tools need to be developed to target the highest contributors and achieve the greatest reduction for the monies spent. Because of the large sediment losses associated with shoreline erosion, the sites with the highest sediment losses have the greatest potential for nutrient contributions, even when the nutrient loading concentrations are average or low. As an example, site PS3 contributes more nutrients due to the high sediment loss and moderate nutrient loading concentrations than site RS3 with low sediment loss and high nutrient loading concentrations. Obviously, the highest contributors would have both high sediment loss and high nutrient loading concentrations. Since data are available in Byrne and Anderson (1977) on the reaches with the highest sediment losses and erosion rates, these reaches should be given the highest priority for implementing shoreline erosion control measures.

The results of this research can also be used to calculate nutrient reduction "credits" for stabilized shoreline sites. To calculate a nutrient reduction credit, the mean nutrient loading concentration for the given landuse at the site and sediment loss information for the reach can be used to calculate a loading rate. Because the land has been stabilized, the loading rate represents a reduction credit of nutrients no longer being input into the Bay. The shoreline stabilization data from the Virginia Bank Erosion Study (Hardaway et. al., in press) will allow the calculation of nutrient reduction credits to the Bay from 1985 to 1990.

VI. CONCLUSIONS

1. The present study verifies that large quantities of nutrients are contributed to the Bay and tributary rivers by shoreline erosion.

2. The mean total phosphorus loading concentration for fossiliferous banks was approximately twice the mean for the non-fossiliferous banks studied.

3. Differences in nutrient loading concentrations were found for different landuse types. Active farmland had the highest nutrient loading concentrations. Wooded land had an equally high mean total nitrogen loading concentration.

4. The nutrient loading data for different landuse types can be used as a management tool to assess a nutrient reduction credit for stabilized shorelines.

VII. RECOMMENDATIONS FOR FURTHER RESEARCH

1. The finding of equally high total nitrogen loading concentrations for the soils of wooded land and active farmland was an unexpected result. Additional research is needed to more thoroughly investigate the relationship between nutrient loading concentrations and landuse, especially for wooded land.

2. The report assumed the calculated nutrient loading concentrations for a given landuse type were consistent within the identified reach. Additional research is needed to determine if this assumption is valid, by evaluating more sampling sites for a given landuse and reach.

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IX. APPENDICES

Appendix A. Sediment and Nutrient Data

Sample	Grain Size %				Nutrient Concentration (mg/g)			
	Gravel	Sand	Silt	Clay	TP	IP	TN	PC
PS1-1	15.3	32.8	50.8	1.1	1.347	0.541	0.510	8.020
PS1-2	16.3	14.9	68.8	0.0	0.415	0.319	0.190	0.790
PS1-3	24.1	4.9	70.8	0.2	0.440	0.035	0.252	1.312
PS1-4	34.8	18.9	45.1	1.2	0.362	0.051	0.410	2.020
PS1-5	28.4	19.6	48.2	3.8	1.616	0.079	2.014	21.797
PS1-6	16.3	51.6	31.9	0.2	0.429	0.019	0.366	2.401
PS1-7	13.5	28.5	58.0	0.0	5.308	2.243	0.550	9.500
PS2-1	5.0	3.6	91.2	0.2	0.022	0.005	0.080	0.270
PS2-2	45.0	11.5	43.4	0.1	0.666	0.014	0.340	2.300
PS2-3	12.1	4.2	80.3	3.4	0.016	0.003	0.040	0.130
PS2-4	7.5	1.6	90.4	0.5	0.035	0.009	0.330	1.110
PS2-5	18.7	3.3	77.7	0.3	0.026	0.002	0.190	1.010
PS2-6	20.2	36.1	42.1	1.6	0.342	0.089	0.780	8.770
PS3-1	32.7	20.8	39.7	6.8	0.193	0.032	0.590	4.670
PS3-2	12.1	1.3	86.5	0.1	0.071	0.007	0.090	0.530
PS3-3	33.6	33.0	32.9	0.5	0.036	0.001	0.090	0.570
PS3-4	20.2	26.6	51.3	1.9	0.060	0.008	0.420	4.030
PS3-5	7.6	1.0	91.3	0.1	0.008	0.000	0.010	0.190
PS3-6	24.8	35.3	39.9	0.0	0.231	0.031	0.730	8.480
PS4-1	57.4	24.1	18.5	0.0	0.089	0.001	0.510	1.750
PS4-2	65.5	21.0	13.4	0.1	0.049	0.000	0.440	2.080
PS4-3	26.2	6.8	66.6	0.4	0.049	0.034	0.280	2.180
PS4-4	18.8	30.7	49.6	0.9	0.208	0.011	0.800	8.360
PS5-1	12.0	2.4	83.3	2.3	1.471	0.027	0.090	0.570
PS5-2	40.8	33.9	24.6	0.7	0.071	0.001	0.420	1.740
PS5-3	9.6	1.9	84.1	4.4	0.049	0.003	0.130	0.680
PS5-4	9.5	29.3	58.0	3.2	0.215	0.035	0.750	10.010
PS6-1	1.0	0.3	97.0	1.7	0.008	0.000	0.030	0.410
PS6-2	15.1	2.9	81.8	0.2	0.014	0.001	0.320	1.710
PS6-3	8.6	3.0	88.2	0.2	0.008	0.001	0.030	0.450
PS6-4	34.5	32.6	32.8	0.1	0.016	0.001	0.160	1.170
PS6-5	13.5	42.5	44.0	0.0	0.062	0.002	1.150	17.190
PS7-1	17.7	6.7	75.6	0.0	0.071	0.005	0.120	0.570
PS7-2	1.5	0.7	97.5	0.3	0.009	0.001	0.020	0.190
PS7-3	11.7	9.3	78.4	0.6	0.093	0.005	0.130	0.700
PS7-4	25.8	41.2	32.9	0.1	0.073	0.001	0.220	1.610
PS7-5	21.1	55.6	23.3	0.0	0.167	0.007	0.820	10.810

Appendix A. Sediment and Nutrient Data (Continued)

Sample	Grain Size %				Nutrient Concentration (mg/g)			
	Gravel	Sand	Silt	Clay	TP	IP	TN	PC
RN1-1	34.6	29.7	35.7	0.0	0.038	0.006	0.088	0.552
RN1-2	4.1	2.5	85.9	7.5	0.042	0.001	0.019	0.270
RN1-3	55.8	36.5	7.7	0.0	0.076	0.001	0.533	2.510
RN1-4	21.5	13.2	65.2	0.1	0.114	0.002	0.081	0.528
RN1-5	12.6	26.2	61.2	0.0	0.045	0.003	0.344	5.568
RN2-1	14.4	4.3	77.2	4.1	2.104	0.005	0.167	1.984
RN2-2	12.7	2.3	85.0	0.0	0.061	0.013	0.060	0.260
RN2-3	21.0	8.2	70.8	0.0	0.085	0.005	0.142	0.799
RN2-4	2.6	0.9	64.8	31.7	0.044	0.001	0.023	0.156
RN2-5	4.0	1.7	90.0	4.3	0.021	0.001	0.010	0.130
RN2-6	20.0	11.0	69.0	0.0	0.058	0.007	0.188	0.789
RN2-7	10.1	21.1	68.5	0.3	0.080	0.005	0.217	2.127
RN2-8	10.3	23.9	65.5	0.3	0.392	0.014	0.648	7.242
RN3-1	1.0	0.8	97.5	0.7	0.009	0.001	0.030	0.230
RN3-2	45.6	24.1	28.8	1.5	0.049	0.000	0.490	2.220
RN3-3	3.8	1.3	94.9	0.0	0.020	0.001	0.040	0.640
RN3-4	17.7	7.2	75.0	0.1	0.022	0.001	0.126	1.659
RN3-5	8.7	22.9	68.3	0.1	0.051	0.002	0.587	15.703
RN4-1	20.7	20.2	59.0	0.1	0.089	0.001	0.178	0.905
RN4-2	53.4	33.1	13.5	0.0	0.163	0.001	0.393	1.912
RN4-3	23.1	18.1	58.7	0.1	0.144	0.003	0.106	7.180
RN4-4	27.7	20.5	48.5	3.3	1.844	0.085	1.508	8.221
RN4-5	11.5	29.7	58.6	0.2	0.162	0.004	0.222	2.482
RN5-1	24.4	31.7	43.9	0.0	0.056	0.004	0.115	0.510
RN5-2	0.7	0.5	81.0	17.8	0.005	0.001	0.010	0.110
RN5-3	2.7	0.5	94.2	2.6	0.018	0.006	0.052	0.315
RN5-4	64.2	19.2	16.0	0.6	0.069	0.003	0.265	2.007
RN5-5	23.0	13.4	62.3	1.3	0.024	0.000	2.188	1.733
RN6-1	5.5	3.4	91.0	0.1	0.082	0.007	0.058	0.362
RN6-2	23.9	9.1	66.9	0.1	0.126	0.002	0.018	0.208
RN6-3	11.2	25.5	62.6	0.7	0.073	0.001	0.268	2.781
RN6-4	6.3	22.9	70.4	0.4	0.073	0.002	0.722	14.045
RN8-1	1.9	1.8	95.7	0.6	0.049	0.005	0.030	0.293
RN8-2	2.1	1.5	95.0	1.4	0.055	0.003	0.350	0.230
RN8-3	23.3	15.1	61.6	0.0	0.410	0.003	0.219	1.394
RN8-4	10.2	21.3	68.4	0.1	0.296	0.004	0.463	5.161

Appendix A. Sediment and Nutrient Data (Continued)

Sample	Grain Size %				Nutrient Concentration (mg/g)			
	Gravel	Sand	Silt	Clay	TP	IP	TN	PC
RN9-1	31.2	26.4	42.4	0.0	0.024	0.002	1.510	37.410
RN9-2	5.8	1.0	92.9	0.3	0.048	0.001	0.022	0.131
RN9-3	3.4	0.4	55.1	41.1	0.005	0.002	0.010	0.090
RN9-4	2.6	0.1	97.1	0.2	0.002	0.001	0.010	0.040
RN9-5	4.1	0.5	78.6	16.8	0.004	0.001	0.010	0.160
RN9-6	3.7	1.2	95.0	0.1	0.003	0.002	0.010	0.090
RN9-7	18.0	7.4	73.8	0.8	0.018	0.006	0.070	0.310
RN9-8	8.0	0.8	91.2	0.0	0.073	0.012	0.030	0.180
RN9-9	4.8	0.6	94.4	0.2	0.015	0.004	0.020	0.160
RN9-10	5.6	0.9	93.5	0.0	0.055	0.005	0.030	0.230
RN9-11	13.3	24.0	62.7	0.0	0.074	0.003	0.160	1.630
RN9-12	10.5	1.3	88.0	0.2	0.060	0.005	0.370	5.420
RS1-1	5.9	1.9	58.4	33.8	0.015	0.003	0.100	1.300
RS1-2	6.9	1.5	90.9	0.7	0.005	0.002	0.020	0.340
RS1-3	28.4	14.5	54.7	2.4	0.034	0.011	0.120	1.290
RS1-4	38.1	23.0	38.6	0.3	0.059	0.003	0.300	2.600
RS1-5	15.3	8.6	75.7	0.4	0.022	0.001	0.120	0.490
RS1-6	22.0	9.3	68.7	0.0	0.021	0.001	0.150	0.550
RS1-7	30.5	16.0	53.5	0.0	0.027	0.003	0.190	0.740
RS1-8	13.7	23.2	63.1	0.0	0.025	0.001	0.130	1.040
RS2-1	10.2	4.8	79.5	5.5	3.880	0.698	0.120	0.920
RS2-2	8.2	4.6	87.1	0.1	1.087	0.140	0.090	0.470
RS2-3	10.2	2.9	86.8	0.1	0.283	0.078	0.130	0.480
RS2-4	20.8	5.2	74.0	0.0	0.073	0.004	0.120	0.430
RS2-5	28.5	7.5	64.0	0.0	0.042	0.002	0.160	0.560
RS2-6	23.5	3.0	73.3	0.2	0.191	0.027	0.480	6.720
RS3-1	5.0	0.7	94.1	0.2	0.033	0.002	0.079	0.259
RS3-2	19.8	14.0	66.2	0.0	0.051	0.003	0.182	1.220
RS3-3	36.9	1.6	61.5	0.0	0.710	0.208	1.095	11.282
RS4-1	9.9	8.7	74.4	7.0	0.475	0.197	0.230	9.060
RS4-2	61.3	36.4	2.3	0.0	0.218	0.028	0.490	8.940
RS4-3	51.0	46.9	1.9	0.2	0.279	0.011	0.720	12.430
RS4-4	60.1	24.5	8.4	7.0	0.218	0.008	0.670	8.800
RS4-5	34.6	17.7	47.6	0.1	0.526	0.011	2.040	1.220
RS4-6	30.7	7.1	62.2	0.0	0.053	0.002	0.300	1.930
RS4-7	14.5	27.0	58.1	0.4	0.231	0.011	0.960	11.530

Appendix A. Sediment and Nutrient Data (Continued)

Sample	Grain Size %				Nutrient Concentration (mg/g)			
	Gravel	Sand	Silt	Clay	TP	IP	TN	PC
RS5-1	0.8	0.4	98.7	0.1	0.055	0.006	0.012	0.097
RS5-2	0.9	0.4	98.3	0.4	0.016	0.002	0.014	0.081
RS5-3	7.3	7.9	84.8	0.0	0.087	0.009	0.043	0.368
RS5-4	20.5	10.3	69.2	0.0	0.152	0.004	0.240	1.584
RS5-5	2.8	1.2	96.0	0.0	0.066	0.005	0.044	0.263
RS5-6	10.3	24.5	65.2	0.0	0.185	0.005	0.633	7.144
RS6-1	55.5	37.0	7.5	0.0	0.138	0.001	0.386	1.909
RS6-2	53.9	26.7	18.5	0.9	0.100	0.014	0.396	1.709
RS6-3	18.9	8.5	72.5	0.1	0.105	0.028	0.091	0.584
RS6-4	13.6	23.1	62.8	0.5	0.540	0.144	0.676	7.631
RS6-5	17.9	20.9	61.2	0.0	0.169	0.055	0.195	1.593
RS7-1	4.0	0.6	94.4	1.0	0.060	0.017	0.220	2.566
RS7-2	11.9	15.4	72.0	0.7	0.038	0.014	0.070	0.284
RS7-3	5.0	1.9	87.8	5.3	0.024	0.005	0.034	0.197
RS7-4	3.3	1.3	95.3	0.1	0.038	0.006	0.025	0.173
RS7-5	5.8	2.2	91.9	0.1	0.022	0.003	0.022	0.248
RS7-6	4.1	1.0	94.5	0.4	0.045	0.007	0.062	0.294
RS7-7	20.3	9.0	70.6	0.1	0.118	0.004	0.224	2.001
RS7-8	2.9	0.5	95.1	1.5	0.020	0.006	0.016	0.125
RS7-9	8.6	17.6	73.6	0.2	0.349	0.017	0.995	11.520
YN1-1	6.1	4.1	89.8	0.0	0.122	0.002	0.929	0.733
YN1-2	29.4	19.0	51.6	0.0	0.188	0.002	0.298	3.647
YN1-3	6.1	17.3	76.5	0.1	0.229	0.008	0.241	3.496
YN2-1	40.6	18.0	40.5	0.9	0.303	0.030	1.236	35.176
YN2-2	33.4	24.4	42.2	0.0	0.092	0.004	0.404	6.527
YN2-3	3.0	0.8	94.2	2.0	0.018	0.001	0.020	0.228
YN2-4	3.3	2.7	93.6	0.4	0.010	0.000	0.052	0.306
YN2-5	67.4	26.1	6.4	0.1	0.163	0.001	0.437	3.527
YN2-6	37.5	19.1	33.4	10.0	0.300	0.001	0.224	24.822
YN2-7	35.4	12.9	51.0	0.7	0.085	0.000	0.270	1.722
YN2-8	7.4	2.0	90.6	0.0	0.074	0.001	0.133	0.438
YN2-9	7.7	2.2	90.1	0.0	0.152	0.002	0.091	0.503
YN2-10	7.8	17.9	74.2	0.1	0.059	0.002	0.093	1.300

Appendix A. Sediment and Nutrient Data (Continued)

Sample	Grain Size %				Nutrient Concentration (mg/g)			
	Gravel	Sand	Silt	Clay	TP	IP	TN	PC
YN3-1	10.9	7.2	81.9	0.0	0.085	0.002	0.079	0.192
YN3-2	11.9	6.1	81.7	0.3	0.089	0.005	0.059	0.132
YN3-3	1.7	0.2	98.0	0.1	0.013	0.000	0.007	0.060
YN3-4	2.4	0.2	95.4	2.0	0.010	0.000	0.014	0.034
YN3-5	7.0	3.0	86.5	3.5	0.055	0.000	0.041	0.089
YN3-6	20.2	12.4	67.4	0.0	0.044	0.000	0.105	0.224
YN3-7	10.9	1.4	87.7	0.0	0.104	0.002	0.076	0.353
YN3-8	7.1	16.5	75.6	0.8	0.140	0.001	0.462	6.019
YN4-1	26.2	14.1	59.7	0.0	0.092	0.001	0.150	0.818
YN4-2	10.7	31.6	57.7	0.0	0.152	0.001	0.559	10.854
YS1-1	5.6	8.4	84.5	1.5	0.067	0.001	0.037	0.194
YS1-2	40.6	24.7	15.2	19.5	0.485	0.001	0.228	1.277
YS1-3	7.7	2.7	89.6	0.0	0.067	0.000	0.104	0.297
YS1-4	12.8	7.2	79.9	0.1	0.214	0.004	0.079	0.316
YS1-5	12.3	16.3	71.3	0.1	0.370	0.014	0.147	1.476
YS1-6	12.4	17.9	55.3	14.4	2.220	0.168	1.152	16.857
JN1-1	4.7	5.0	90.3	0.0	0.105	0.004	0.057	0.333
JN1-2	22.9	19.7	57.3	0.1	0.183	0.003	0.176	0.638
JN1-3	41.8	28.0	30.0	0.2	0.291	0.004	0.391	1.518
JN2-1	43.5	23.0	27.0	6.5	0.116	0.003	0.223	0.567
JN2-2	14.1	29.1	55.7	1.1	0.062	0.004	0.109	0.435
JN2-3	44.0	19.6	36.2	0.2	0.039	0.001	0.289	21.155
JN2-4	16.7	19.1	62.2	2.0	0.144	0.001	0.129	0.663
JN2-5	43.7	24.3	32.0	0.0	0.058	0.001	0.238	0.945
JN2-6	25.3	6.3	68.1	0.3	0.044	0.001	0.187	1.046
JN2-7	68.1	28.9	2.9	0.1	0.033	0.003	0.540	4.662
JN2-8	71.9	26.5	1.6	0.0	0.087	0.002	6.440	6.346
JN3-1	69.5	21.3	8.8	0.4	0.111	0.007	3.704	56.127
JN3-2	21.9	35.2	42.9	0.0	0.061	0.005	0.499	2.268
JN3-3	7.6	4.9	87.5	0.0	0.025	0.001	0.074	0.607
JN3-4	43.1	28.0	28.9	0.0	0.047	0.001	0.395	2.367
JN3-5	28.3	20.2	51.3	0.2	0.047	0.002	0.247	1.148
JN3-6	46.4	45.1	8.4	0.1	0.025	0.002	0.570	2.170
JN3-7	46.2	42.0	11.8	0.0	0.024	0.001	0.340	1.389
JN3-8	28.0	60.3	11.5	0.2	0.105	0.004	0.100	18.065

Appendix A. Sediment and Nutrient Data (Continued)

Sample	Grain Size %				Nutrient Concentration (mg/g)			
	Gravel	Sand	Silt	Clay	TP	IP	TN	PC
JN4-1	18.9	24.1	56.9	0.1	0.398	0.006	0.290	1.170
JN4-2	22.5	18.0	59.5	0.0	0.426	0.017	0.250	0.790
JN4-3	41.0	43.4	15.6	0.0	0.396	0.011	0.410	1.210
JN4-4	35.9	45.4	18.7	0.0	0.583	0.012	0.512	3.203
JN4-5	20.9	52.7	25.3	1.1	0.510	0.025	2.310	27.700
JN5-1	0.8	0.6	96.5	2.1	0.082	0.002	0.172	0.102
JN5-2	3.7	4.0	92.3	0.0	0.087	0.003	0.215	0.145
JN5-3	28.0	31.7	40.3	0.0	0.187	0.005	0.724	0.668
JN5-4	24.3	11.5	63.8	0.4	0.442	0.019	1.091	0.997
JN5-5	26.0	22.0	51.7	0.3	0.455	0.012	0.404	2.573
JN5-6	7.3	28.6	63.8	0.3	0.406	0.018	2.017	24.198
JS1-1	36.8	53.5	9.7	0.0	0.151	0.024	0.620	7.570
JS1-2	27.8	27.5	44.7	0.0	0.061	0.017	0.318	2.985
JS1-3	17.3	23.9	58.7	0.1	0.018	0.002	0.098	0.721
JS1-4	49.0	34.7	11.3	5.0	0.176	0.002	0.502	1.765
JS1-5	41.8	29.9	27.4	0.9	0.039	0.001	0.338	1.551
JS1-6	50.3	23.9	24.9	0.9	0.086	0.002	0.949	23.369
JS2-1	3.7	0.8	93.4	2.1	0.016	0.001	0.011	0.096
JS2-2	3.6	0.8	54.8	40.8	0.009	0.001	0.014	0.075
JS2-3	7.2	1.1	91.7	0.0	0.013	0.001	0.014	0.164
JS2-4	24.0	23.2	52.5	0.3	0.049	0.002	0.197	0.878
JS2-5	42.1	50.1	7.8	0.0	0.019	0.001	0.319	1.797
JS2-6	19.6	10.3	69.5	0.6	0.054	0.001	0.153	1.077
JS2-7	21.9	10.4	63.7	4.0	0.046	0.001	0.183	1.010
JS2-8	51.3	23.5	25.2	0.0	0.019	0.001	0.263	1.330
JS2-9	62.8	29.4	7.8	0.0	0.035	0.001	0.550	5.838
JS2-10	26.3	41.6	31.1	1.0	0.243	0.014	0.424	9.765
JS3-1	32.2	32.0	35.7	0.1	0.286	0.006	0.328	1.496
JS3-2	11.6	43.0	45.4	0.0	0.296	0.003	0.071	0.804
JS4-1	3.3	1.1	95.3	0.3	0.106	0.005	0.002	0.025
JS4-2	21.2	24.4	54.4	0.0	0.251	0.006	0.017	0.073
JS4-3	47.6	39.8	11.9	0.7	0.363	0.005	0.573	4.343
JS4-4	37.9	44.7	17.4	0.0	0.352	0.004	2.264	24.375
JS4-5	11.5	49.9	38.0	0.6	0.443	0.013	0.133	0.512

Appendix A. Sediment and Nutrient Data (Continued)

Sample	Grain Size %				Nutrient Concentration (mg/g)			
	Gravel	Sand	Silt	Clay	TP	IP	TN	PC
JS5-1	29.9	47.8	22.3	0.0	0.098	0.011	0.680	6.780
JS5-2	30.4	28.4	41.2	0.0	0.035	0.011	0.160	2.180
JS5-3	9.3	8.9	81.8	0.0	0.030	0.004	0.160	1.910
JS5-4	2.6	0.7	96.7	0.0	0.007	0.002	0.020	0.210
JS5-5	19.8	10.3	69.9	0.0	0.025	0.001	0.150	0.890
JS5-6	16.5	14.3	68.7	0.5	0.018	0.001	0.320	2.190
JS5-7	4.7	44.0	50.5	0.8	0.122	0.007	1.880	35.170
JS6-1	13.7	24.0	56.9	5.4	0.380	0.022	0.214	16.201
JS6-2	13.1	24.5	61.6	0.8	0.377	0.021	0.154	16.709
JS6-3	12.4	17.8	67.8	2.0	0.037	0.012	0.160	16.098
JS6-4	16.6	16.7	66.7	0.0	0.024	0.013	0.157	1.152
JS6-5	25.2	14.9	59.8	0.1	0.133	0.034	0.231	1.372
JS6-6	11.9	22.5	65.2	0.4	0.277	0.035	0.387	5.124
JS6-7	13.4	23.8	60.3	2.5	0.360	0.028	0.677	7.443
JS7-1	20.3	26.1	52.4	1.2	0.946	0.078	0.400	11.490
JS7-2	23.1	35.4	39.2	2.3	0.343	0.001	0.370	30.400
JS7-3	12.9	25.3	35.5	26.3	0.383	0.001	0.430	70.900
JS7-4	33.4	14.7	51.9	0.0	1.184	0.027	0.130	0.650
JS7-5	40.2	24.2	35.5	0.1	0.035	0.001	0.380	1.800
JS7-6	14.1	3.9	81.5	0.5	0.015	0.001	0.060	0.470
JS7-7	16.9	3.5	79.5	0.1	0.013	0.000	0.040	0.350
JS7-8	40.1	11.2	48.7	0.0	0.024	0.001	0.130	0.890
JS7-9	41.2	6.7	52.1	0.0	0.010	0.001	0.670	0.660
JS7-10	8.6	19.5	71.9	0.0	0.051	0.003	0.320	4.510
PI1-1	12.1	8.0	79.8	0.1	0.042	0.005	0.263	2.541
PI1-2	10.8	3.0	86.2	0.0	0.036	0.001	0.110	0.676
PI1-3	24.2	17.1	58.1	0.6	0.027	0.001	0.305	2.740
PI1-4	14.4	27.2	55.6	2.8	0.129	0.016	0.969	15.310
WS1-1	17.8	34.1	47.9	0.2	0.145	0.003	0.207	1.484
WS1-2	13.0	30.8	56.1	0.1	0.544	0.067	1.057	12.927
ES1-1	9.9	5.4	84.7	0.0	0.026	0.003	0.070	0.310
ES1-2	6.1	2.5	91.4	0.0	0.036	0.012	0.070	0.480
ES1-3	18.9	13.8	67.3	0.0	0.144	0.010	0.160	1.220
ES1-4	31.6	32.8	35.6	0.0	0.087	0.003	0.270	2.260
ES1-5	9.9	30.6	59.5	0.0	0.142	0.002	1.500	20.270

Appendix A. Sediment and Nutrient Data (Continued)

Sample	Grain Size %				Nutrient Concentration (mg/g)			
	Gravel	Sand	Silt	Clay	TP	IP	TN	PC
ES2-1	4.9	1.5	93.6	0.0	0.053	0.011	0.040	0.790
ES2-2	7.6	0.9	91.5	0.0	0.055	0.018	0.050	0.640
ES2-3	7.5	0.7	67.4	24.4	0.116	0.018	0.020	0.550
ES2-4	22.8	37.2	40.0	0.0	0.051	0.002	0.210	1.270
ES2-5	9.4	28.3	61.8	0.5	0.462	0.275	0.530	5.710
ES3-1	13.1	8.6	78.0	0.3	0.145	0.007	0.110	0.480
ES3-2	20.7	31.8	47.5	0.0	0.102	0.002	0.150	1.760
ES3-3	10.6	29.3	60.1	0.0	0.704	0.002	0.350	0.250
ES3-4	2.9	0.4	96.7	0.0	0.009	0.002	0.010	0.250

Appendix B. GIS Coordinates

Site	Quadrangle	North	East
PS1	Colonial Beach South	4229800	330400
PS2	St. Clements Island	4223750	350800
PS3	Kinsale	4217150	361850
PS4	Kinsale	4209350	366500
PS5	Heathsville	4202000	377500
PS6	Burgess	4199950	383050
PS7	Burgess	4195450	389650
RN1	Irvington	4169300	370350
RN2	Urbanna	4171300	364600
RN3	Urbanna	4175700	362700
RN4	Morattico	4187050	352400
RN5	Tappahannock	4197100	343650
RN6	Morattico	4191500	346900
RN8	Morattico	4191600	346900
RN9	Deltaville	4164550	378700
RS1	Wilton	4163400	369800
RS2	Saluda	4163650	364650
RS3	Urbanna	4174650	359150
RS4	Morattico	4183200	349050
RS5	Dunnsville	4187650	345600
RS6	Urbanna	4171050	360400
RS7	Morattico	4185850	346650
YN1	Clay Bank	4131400	359900
YN2	Williamsburg	4137300	355600
YN3	Gressitt	4139450	353850
YN4	Gressitt	4150350	346100
YS1	Toano	4150450	342500
JN1	Surry	4123200	334400
JN2	Hog Island	4120750	350150
JN3	Yorktown	4116350	356450
JN4	Claremont	4122750	328900
JN5	Claremont	4124150	326200
JS1	Bacons Castle	4105750	352300
JS2	Hog Island	4111100	351950
JS3	Hog Island	4115650	352000
JS4	Brandon	4124400	323750
JS5	Benns Church	4095700	361900
JS6	Mulberry Island	4099150	358600
JS7	Bacons Castle	4099800	354850

Appendix B. GIS Coordinates (Continued)

Site	Quadrangle	North	East
PI1	Mathews	4150450	382400
WS1	Deltaville	4151600	386800
ES1 ES2 ES3	Franktown Franktown Elliotts Creek	4144950 4150500 4119950	413900 415250 410150