Delaware River Rooted Aquatic-Plant Biomass Study From Port Jervis, N.Y. (Route 84 Bridge) To Milford, PA (Route 206 Bridge)

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Delaware River Basin Commission

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In cooperation with the National Park Service:
Upper Delaware Scenic and Recreational River and the
Delaware Water Gap National Recreation Area,
and the U.S. Geological Survey

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The New Jersey district office of the U.S. Geological Survey provided laboratory facilities for biomass analysis. All biomass analyses were performed by the Delaware River Basin Commission staff.

Unit Conversions

From	To	Multiply by:
pound	kilogram	0.4535
cubic feet per second	cubic meter per second	0.0283
feet per second	meter per second	0.3048
kilogram	gram	1,000
square feet	square meter	0.0929
cubic feet	cubic meter	0.0283
mile	kilometer	1.6093
kilometer	meter	1,000
meter	centimeter	100
mile	feet	5,280

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INTRODUCTION

Since 1984, the Delaware River Basin Commission (DRBC), in cooperation with the Delaware Water Gap National Recreation Area (DWGNRA) and the Upper Delaware Scenic and Recreational River (UDSRR) units of the National Park Service, and the U.S. Geological Survey, has been collecting water quality and flow data from the Delaware River and the adjoining tributaries. The monitoring program spans a 121 mile reach of the Delaware River from Hancock, N.Y. to the Delaware Water Gap. This effort is known as the Scenic Rivers Monitoring Program (SRMP). The goal of the program is to monitor the waterways within the National Park Service boundaries as well as an 8-mile reach of river between the two National Park Service boundaries and check the data for unusual variation over time. In 1992 the Delaware River Basin Commission adopted "Special Protection Waters" regulations to protect the "existing" water quality of this reach of the Delaware River and the connecting tributaries.

Changes to water quality can emanate from many different sources. Natural sources include geologic transformations, animal wastes, and the decomposition of detritus. Anthropogenic sources include point-source discharges from wastewater treatment plants, commercial businesses, and industry; and non-point source contamination from road maintenance, agricultural practices, and residential home and yard maintenance. Atmospheric deposition contains both natural and man-induced chemical constituents that may degrade water quality. Both surface and ground water are susceptible to degradation from each of the sources of contamination. Nutrients (primarily nitrogen and phosphorus) entering a waterway can stimulate excessive aquatic plant blooms that may restrict recreational use, impair the natural aesthetics, and adversely disturb the native habitat.

To better understand the relationships between the multiple sources of contamination and the possible range of effects from these potential alterations to the aquatic environment, the DRBC is using the water quality and flow data collected from the SRMP to calibrate watershed and open-channel computer models. The QUAL2EU model (Brown and Barnwell, 1987) is an open channel model that is being calibrated for simulating changes to pollutant loadings and flow in the Delaware River reach from Millrift, PA (river mile 258.4) to the Delaware Water Gap (river mile 209.4). River mileage is measured upstream from the mouth of Delaware Bay (Delaware River Basin Commission, 1988 and Kratzer, 1994). As with most models of lotic systems, the aquatic plant productivity simulation routine assumes that the main contribution is from suspended algae (phytoplankton). This assumption creates linear longitudinal changes to dissolved oxygen, pH, and nutrients. However, the reach of the Delaware River from Millrift, PA to the Delaware Water Gap can support discontinuous dense growths of rooted aquatic plants (macrophytes). Irregularly-spaced plant beds cause temporal and spatial variability in dissolved oxygen, pH, nutrients, and average flow velocities, both laterally and longitudinally.

The Texas Water Commission (1990) modified the QUAL-II model (one of the former versions of the QUAL2EU model) to simulate the productivity of rooted aquatic plants. The new model is called the QUAL-TX model. Results of this study will be used to calibrate the QUAL-TX model or a similar rooted aquatic plant simulation program.

From August 25 to September 2, 1997, the DRBC, in conjunction with staff from the DWGNRA and the UDSRR, conducted a macrophyte biomass study on a reach of the Delaware River extending from the route 84 bridge between Matamoras, PA and Port Jervis, N.Y. (river mile 253.65) to the route 206 bridge at Milford, PA (river mile 246.00). The study reach was divided into 6 subreaches that had obvious landmarks at the upstream and downstream boundaries. The subreaches were also selected to coincide with those of an earlier biomass study that was performed on a segment of the current study reach in 1989.

Table 1 defines the length and bottom-area coverage of each subreach. **Figures 1 to 7** show the study site locations.

Table 1. Subreach length (miles) and bottom area (square feet, ft^2). Bottom area was based on a QUAL2EU model run for the Delaware River at a flow of 1,800 cubic feet per second, referencing the U.S. Geological Survey stream flow gages at Port Jervis, N.Y. and Montague, N.J..

Subreach	Upstream Boundary (river mile)	Downstream Boundary (river mile)	Subreach length (miles)	Subreach bottom area (ft^2)
1	253.82	252.82	1.00	3,492,818
2	252.82	251.36	1.46	4,865,958
3	251.36	249.39	1.97	6,685,554
4	249.39	248.89	0.50	1,405,875
5	248.89	247.17	1.72	5,808,898
6	247.17	246.12	1.05	3,218,237

Water quality and flow data within the study reach have shown unusual fluctuations in nutrient, pH, dissolved oxygen, and flow velocity levels. These fluctuations have consistently occurred during the macrophyte growing season (May thru September) and are indicative of aquatic plant productivity.

The following physical and chemical characteristics were observed in the river reach during the 1997 study.

- River flow at the U.S. Geological Survey stream gage at Montague, N.J. averaged approximately 1,700 cubic feet per second (cfs).

- Average water depths at plant bed locations ranged from 1 to 6 feet.

- Reach-average flow velocities ranged from 1.1 to 2.1 feet per second (fps). These data were obtained from the QUAL2EU model calibration and do not include pooled water. Plant beds located in deeper pools and runs had slower velocities.

- Plant bed substrate was usually a mixture of silt, sand, cobble, and boulder with a single occurrence of bedrock. Nearly all plant beds had a large percentage of cobble combined with lesser amounts of the other constituents. Genus-specific habitat characteristics are presented in **Appendix A**.

Study Location

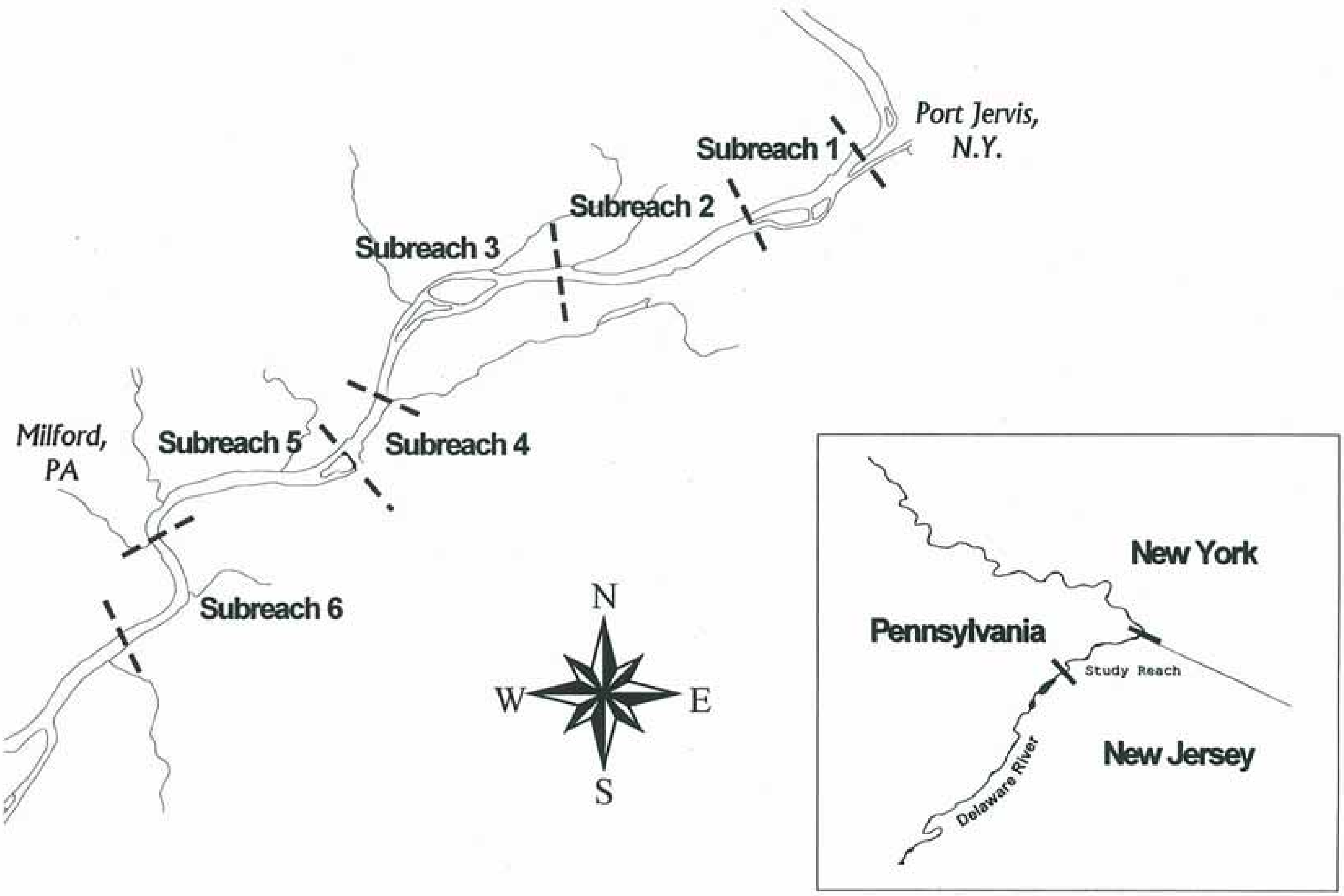

Figure 1.

Delaware River - Subreach 1

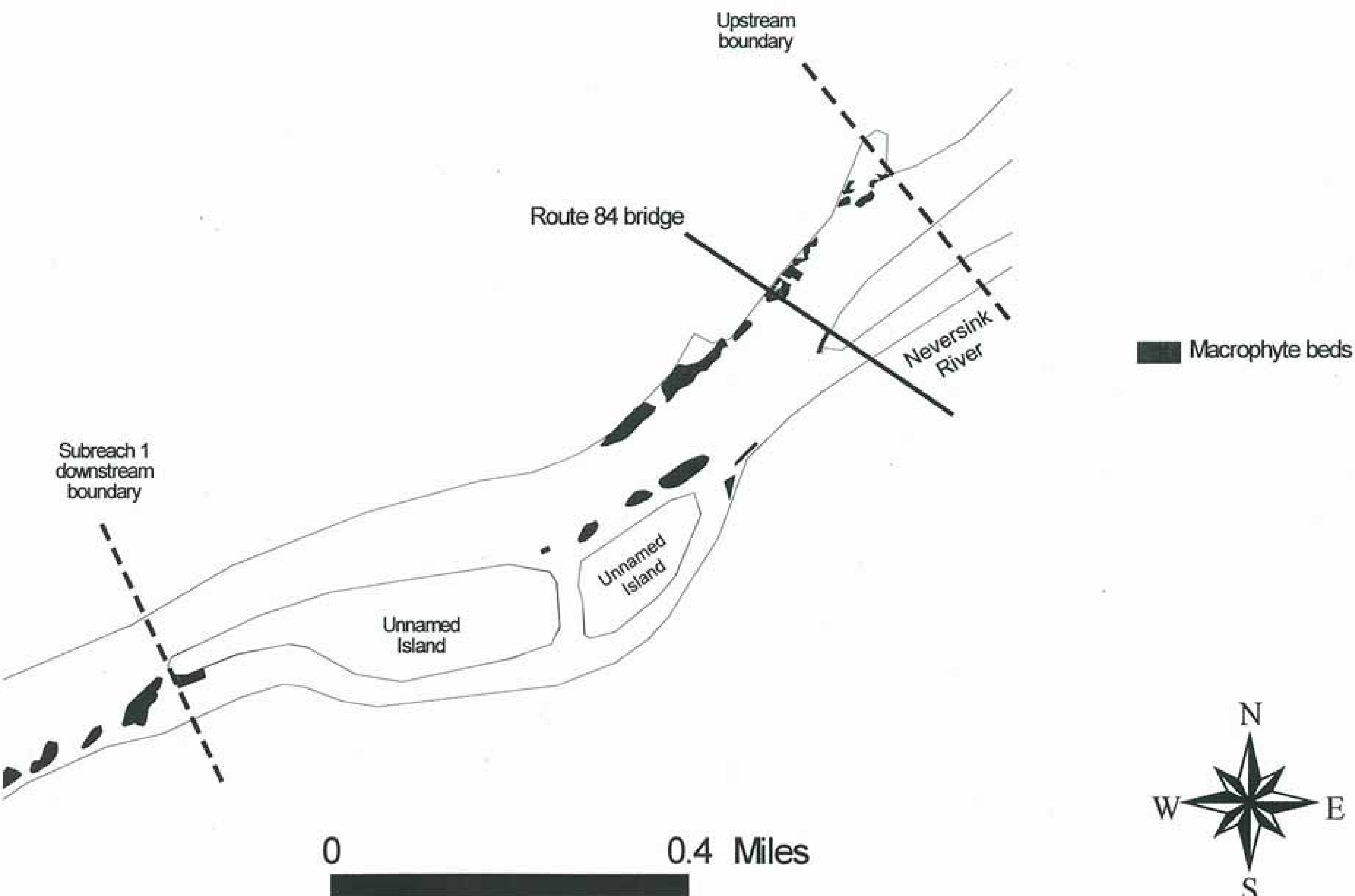

Figure 2.

Delaware River - Subreach 2

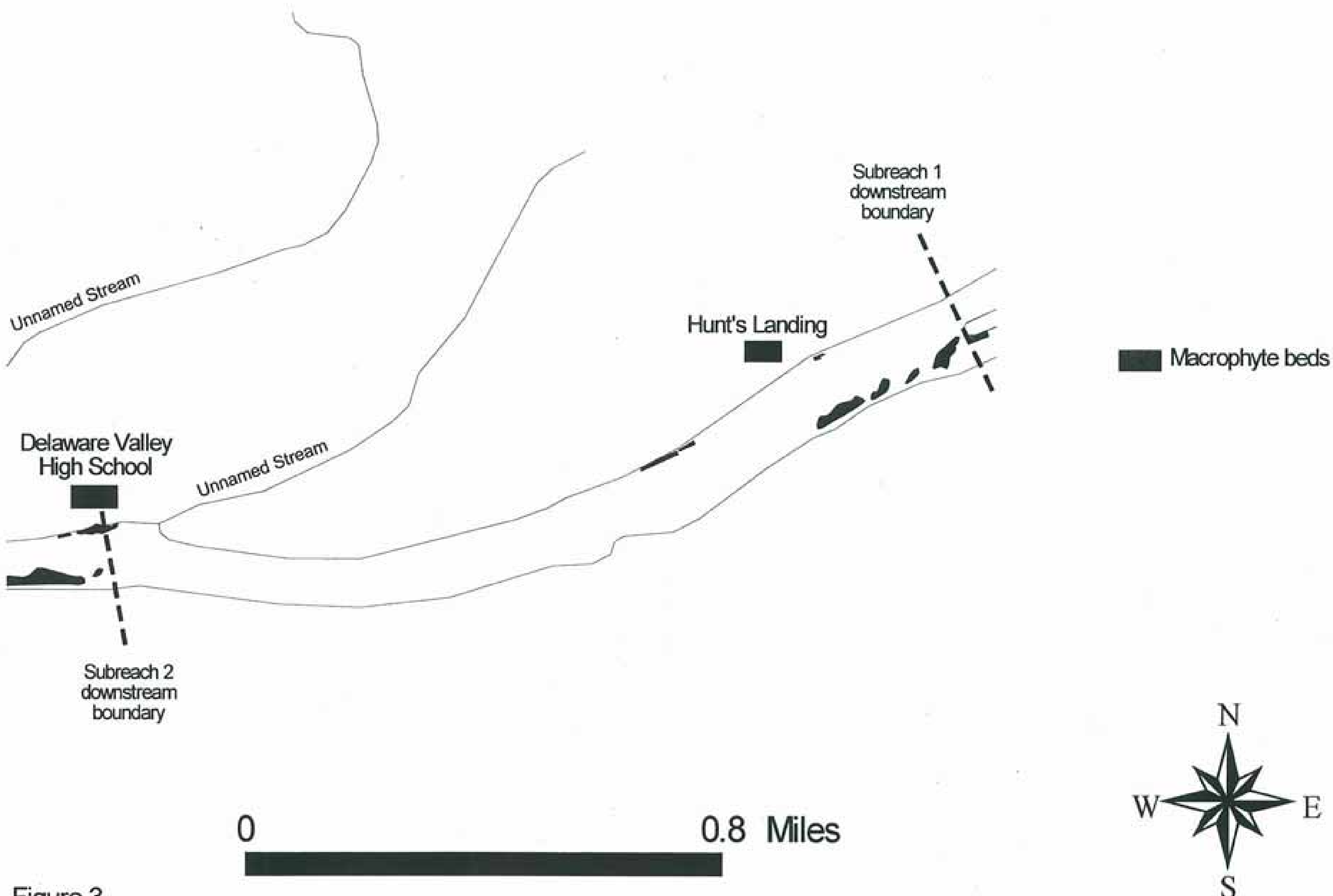

Figure 3.

Delaware River - Subreach 3

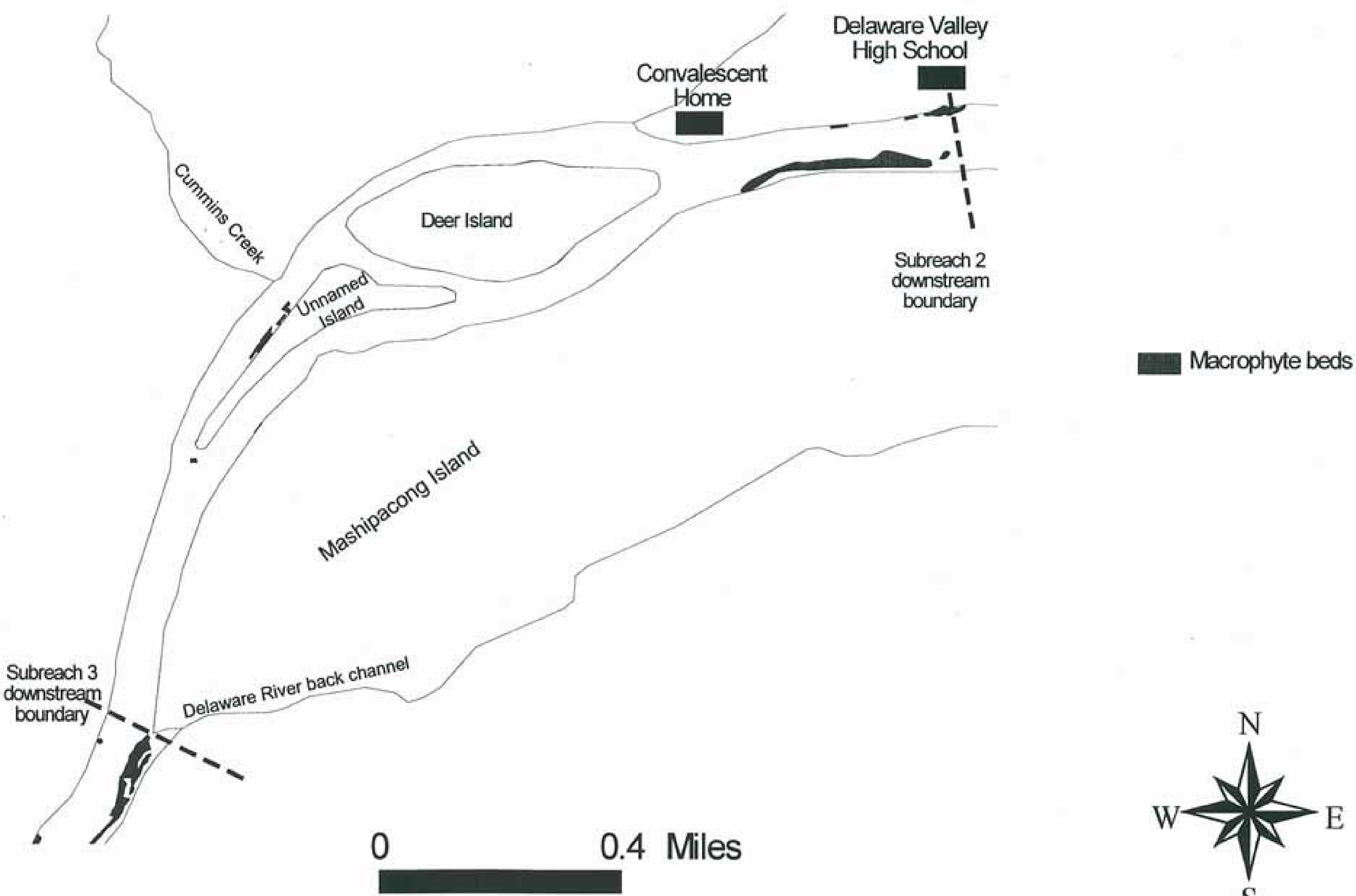

Figure 4.

Delaware River - Subreach 4

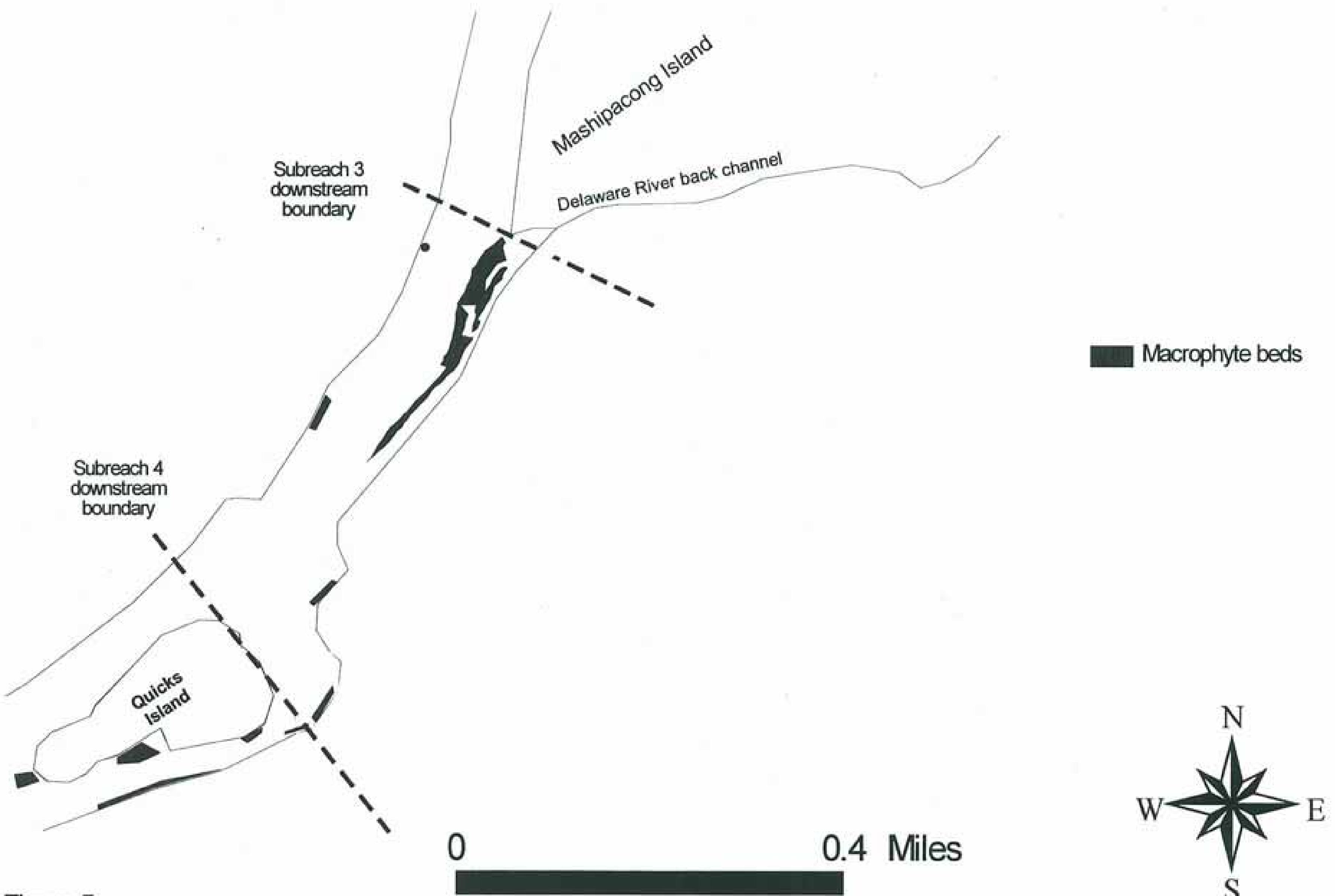

Figure 5.

Delaware River - Subreach 5

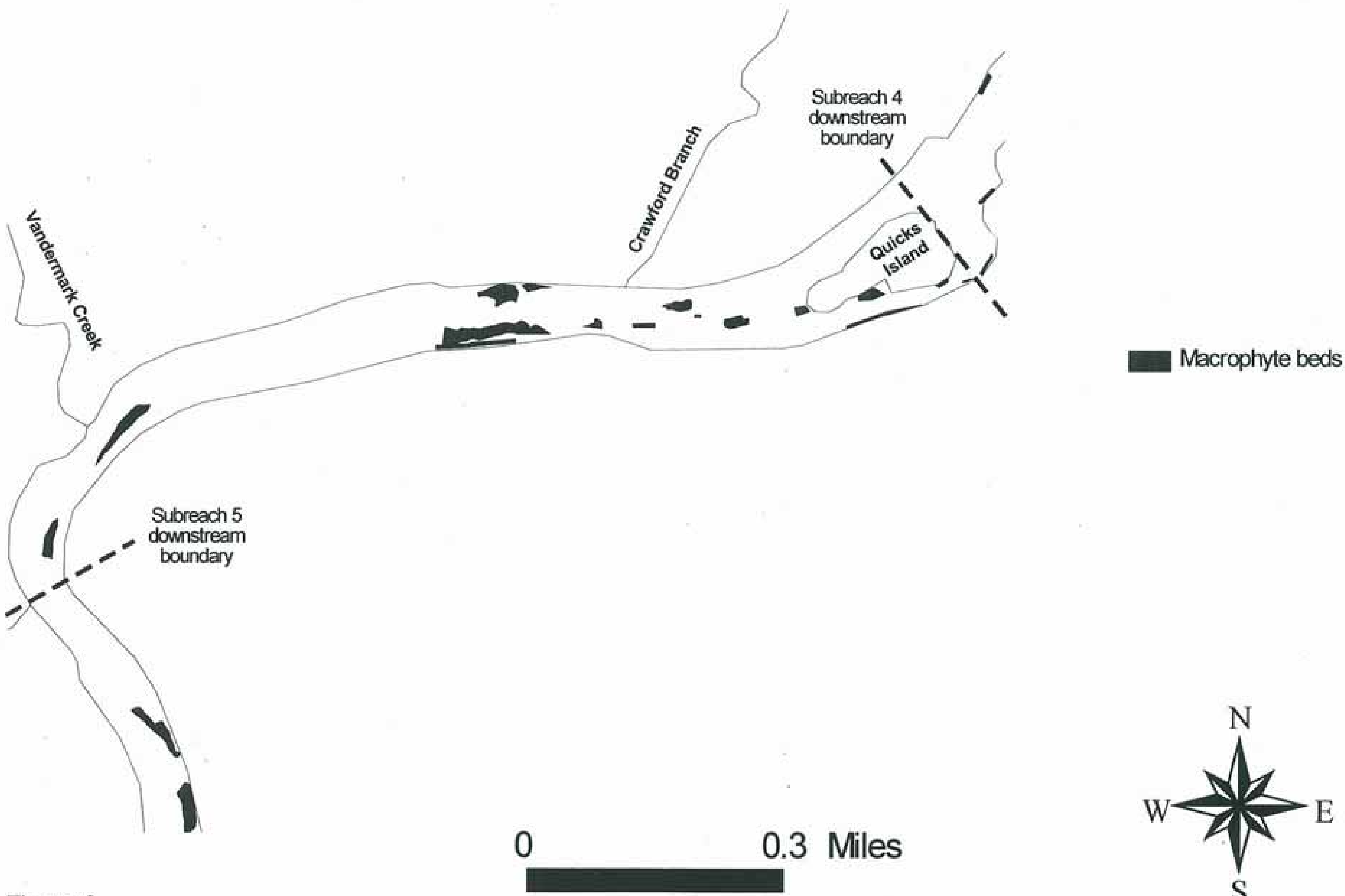

Figure 6.

Delaware River - Subreach 6

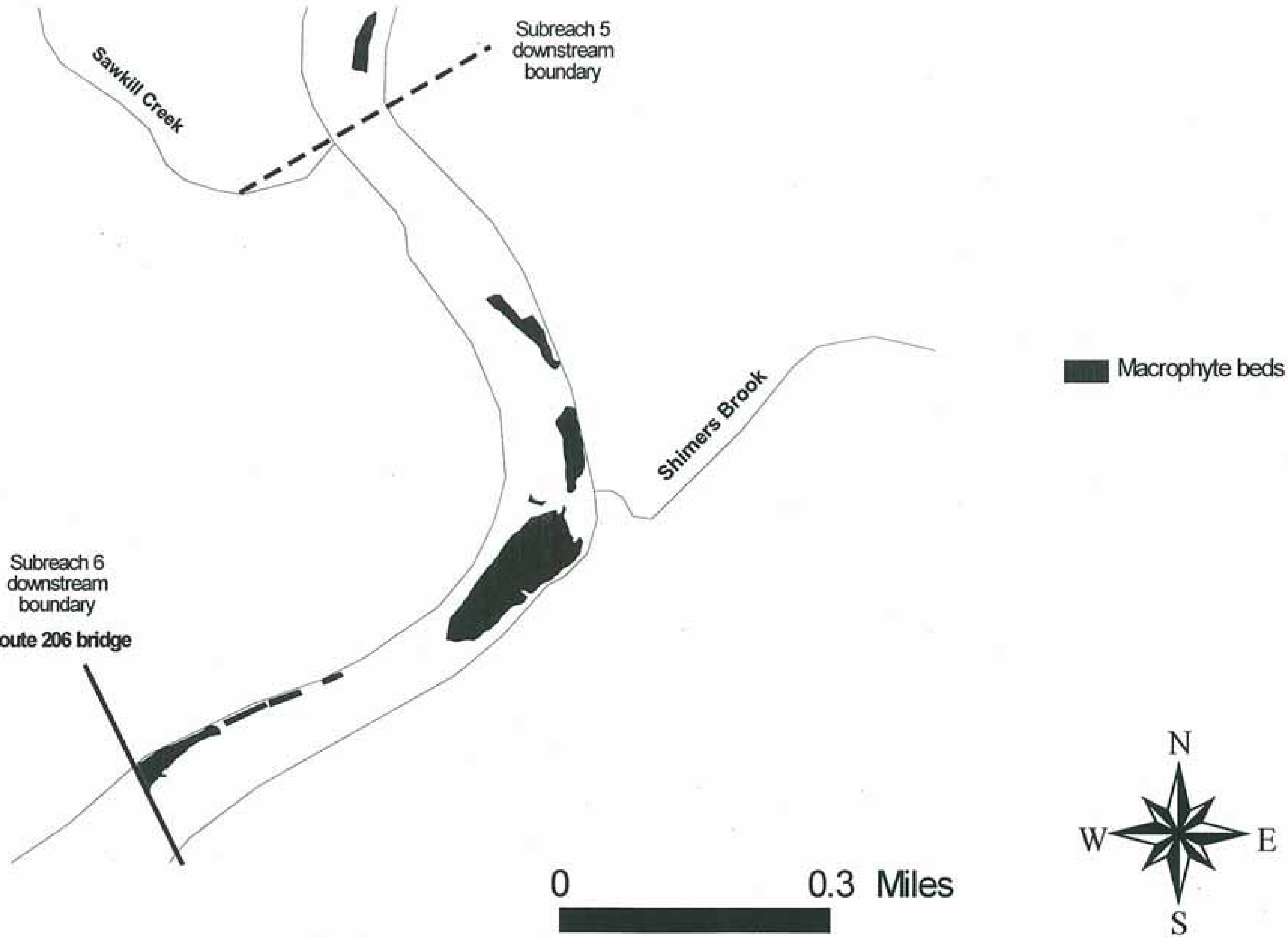

Figure 7.

- Phosphate as P and NO_2+NO_3 as N averaged approximately 0.02 milligram per liter (mg/l), and 0.24 mg/l, respectively.

- Turbidity and water temperature averaged approximately 5 FTU and 23 °C, respectively.

The primary objectives of the 1997 study were 1) to develop effective and efficient plant-bed measurement techniques, 2) to compare the locations and densities of aquatic macrophytes to the 1989 study, and 3) to use the data for calibration of a stationary aquatic-plant productivity and water quality model.

BACKGROUND

During the day, plants produce oxygen (photosynthesis), while continuously using oxygen and releasing carbon dioxide for metabolic functions (respiration). The overall effect is called net photosynthesis. During the peak growing season, oxygen uptake is less than what is produced during photosynthesis. At night, respiration continues as carbon dioxide is released and oxygen is consumed. Since carbonic acid concentrations are proportional to the amount of carbon dioxide released to the water, the water pH fluctuates accordingly. Usually, the pH levels directly follow the dissolved oxygen levels. The photosynthesis and respiration rates are directly proportional to ambient water temperature, nutrient availability, and the intensity of solar radiation. Changes in ambient dissolved oxygen, pH, and nutrients from aquatic plant productivity are usually extremely variable within and evident for some distance downstream of the plant beds. Larger plant beds affect a larger section of the stream.

Aquatic plants take in and store nutrients (mainly ammonia: NH_3, or ammonium: NH_4^+, nitrate: NO_3, phosphate: PO_4, and carbon) from the water through their stems and leaves and from the sediments through their roots. Rooted aquatic macrophytes obtain nearly all of their nutrients from the sediment (Barko and Smart, 1986; Barko et. al., 1991; and Doust et. al., 1994). Landers (1982) found that macrophytes can release up to 2.2 percent and 18 percent of the total allochthonous NO_3^-+NO_2^-+NH_4^+ nitrogen and total phosphorus, respectively, to a waterway during senescence and decay. Much of the nutrients released by macrophytes are taken up by phytoplankton and periphyton, creating an end-of-the-season shift in plant taxa density.

Unmanaged inputs of nutrients, primarily phosphorus and nitrogen, to a waterway may cause extensive aquatic plant blooms. Large plant blooms can suppress recreational opportunities, reorient the flow path(s), and cause large fluctuations in dissolved oxygen and pH over a 24 hour cycle from photosynthesis and respiration. Fluctuations in dissolved oxygen and pH can be deleterious to aquatic organisms. Dissolved oxygen levels of less than 6 mg/l begin to stress salmonid species of fish. Dissolved oxygen levels less than 2 mg/l begin to shift the aquatic community toward anaerobic conditions. Low levels of pH (acidic conditions) can directly affect aquatic organisms by limiting metabolic functions. Low pH can also indirectly affect aquatic organisms by optimizing the conditions for conversion of insoluble metals in the sediments to soluble forms. Soluble forms of metals are more readily released from the sediments to the water column where they can accumulate in the tissues of aquatic organisms. Metal accumulation can impair the growth and reproduction of most fish, invertebrates, and plants.

Aquatic plants are beneficial as natural filters, habitat, and food. Many fish use the plant beds for feeding, spawning, and refuge from predators. Aquatic plants not only remove nutrients from the water during the growing season, but they also remove metals, polychlorinated biphenyls (PCBs), and organotoxins during normal metabolic functions (Doust et. al., 1994; Whitton and Kelly, 1995; and Rybicki, 1998). In this respect, Whitton and Kelly (1995) describe how aquatic plants have been used as bioindicators for water pollution studies. The high level of accumulation of contaminants by plants allows them to be used as better indicators of pollution sources than macroinvertebrates and conventional water analyses. Water fowl and some terrestrial animals feed on the plants as well as the organisms residing on the plants, ingesting whatever toxicants these food sources have accumulated.

Different macrophyte taxa require different types of habitat for optimal growth. All photosynthetic aquatic plants grow best in unshaded areas that have low to moderate predation and competition, sufficient water depth and clarity, adequate water temperature, and a continuous nutrient supply. Other factors that affect plant growth include flow velocity and substrate composition. Barko and Smart (1986) determined that some macrophytes may have limited growth in substrates with high-density sands or with organic content greater than 20 percent. French and Chambers (1996) found that Elodea canadensis occurred most often at water depths between 4.9 and 9.8 feet, in silty substrates, and in flow velocities of less than 0.66 feet per second (fps). E. canadensis had the dominant density (biomass) in all reaches having flow velocities less than or equal to 1.3 fps. Haslam (1978) and The Nature Conservancy (1994), described the habitat of E. canadensis as variable. Most often, Elodea seeks silty channels in still and slow-moving, clear water with some eutrophic influence. Potamogeton perfoliatus prefers semi-eutrophic streams with medium to higher flows and firm substrate. Potamogeton crispus also prefers a semi-eutrophic or eutrophic environment with medium flows in shallow silt over a firm substrate.

Larger plant beds can slow the average reach velocity, thus allowing longer reaction times for water quality transformations, dispersion, and particle settling (Gregg and Rose, 1982; Kratzer, 1994; Biggs, 1996; and Rybicki, 1998). The slowed velocities require a larger cross section to provide the same conveyance for the water flow. Rybicki (1998) explained how dense aquatic plant growths can cause large interferences and potential errors in U. S. Geological Survey records for water depth versus discharge relationships. Unusually slow velocities for the reach of the Delaware River from Port Jervis, N.Y. to the route 206 bridge were apparent during the Upper and Middle Delaware River time-of-travel and dispersion studies in 1991 (White and Kratzer, 1994; and Kratzer, 1994). Extensive plant growth was observed during the time-of-travel study at the route 209 bridge between Port Jervis, N.Y. and Matamoras, PA. The plant mass restricted most of the river flow to the Pennsylvania side of the channel. During the 1997 plant-biomass study, the plant mass at this same site was minimal.

By measuring the genus-specific biomass densities within, and nutrient, dissolved oxygen, water temperature, and flow at an upstream and a downstream location on a river reach, a plant productivity model can be calibrated. Observed biomass, nutrient, and dissolved oxygen values are matched against the simulated values to validate the model. A calibrated model can then be used to predict the rooted aquatic plant response to a given increase or decrease in nutrient loadings and the subsequent variability that the plant productivity may exert on the dissolved oxygen, pH, nutrient, and flow velocity levels.

METHODS

The following methods were used to collect plant samples, measure areal coverage, measure plant dry weight, and determine biomass for the dominant plant genera within the study reach.

Plant Collection

Macrophyte biomass samples were collected for each dominant genera from a square-foot (ft^2) area. A square-foot metal grid was placed around the base of a selected plant bed to delineate the plant sample area. Plant beds that appeared to contain a single genus and visually covered 100 percent of the grid area were selected for sampling. The method required two people for sample collection. Once the grid was positioned around the plant mass, one person gently loosened the sediment around the plant roots within the grid to a depth of up to approximately 6 inches. The plants were gently uprooted and placed into a zip-lock freezer bag, supplied by a second person who was positioned downstream of the sampling site. The downstream person was also responsible for collecting plant material that strayed from the sampling grid. After the plant sample was collected, the zip-lock bag was placed into a cooler with ice for preservation. The samples were kept refrigerated until they were analyzed. Average plant lengths were measured during sample collection and ranged from 0.5 to 6 feet. Water depths at one-half foot intervals were targeted for sample collection. Snorkeling gear was used when collecting the deeper water samples. **Table 2** presents the data for plant genus, average plant length (inch), and shoot and root dry weight (gram).

Areal Coverage Measurement

Copper pipes, ten feet long by one-half inch diameter, were marked at one-foot intervals. These were used to manually measure the length and width of the smaller plant beds. Larger plant beds were marked along the perimeter with small floats that were deployed from a canoe. The floats were made from 3 inch diameter styrofoam balls painted fluorescent orange and anchored to a metal weight with nylon cord. After the bed was marked, a second canoe rigged with a global positioning system (GPS) was guided along the floats to collect the areal coverage data. The GPS was set to record position data using the Universal Transverse Mercator (UTM) coordinate system with the 1927 North American Datum (NAD-27). Attribute data for plant genus, average plant length, percent areal coverage by each plant genus, average water depth, substrate type, and a mapping code were also recorded with the plant bed coordinates. Following the GPS data collection, the floats were retrieved and readied for use at the next site.

Plant beds were partitioned for measurements according to average water depth, average plant length, percent plant coverage, and the consistency of plant genus mixes throughout the bed. The larger beds were subdivided when necessary to provide uniform conditions for the measurements.

Global positioning system data were corrected for satellite-timing errors by comparing the data to those from a GPS base-station, operated by the state of New Jersey in Trenton, N.J.. The base-station data were downloaded from the State's electronic bulletin board and used to differentially correct the plant-bed data.

Table 2. Square-foot biomass samples for Elodea, Potamogeton, and Vallisneria.
* Possible error in sample collection, considered as outlier.

Genus	Average plant length (inch)	Shoot dry weight (gram)	Root dry weight (gram)
Elodea	4	6.72	0.41
Elodea	12	17.24	0.87
Elodea	12	9.90	0.42
Elodea	18	19.10	1.13
Elodea*	18	28.63	0.85
Elodea	20	16.74	0.75
Elodea	24	14.77	0.41
Elodea	29	20.38	0.79
Elodea	30	23.42	1.09
Elodea	30	24.16	0.62
Elodea	45	29.62	0.90
Potamogeton	12	12.01	1.88
Potamogeton	12	9.40	1.73
Potamogeton	14	8.59	1.15
Potamogeton	18	16.08	2.94
Potamogeton	18	11.65	1.60
Potamogeton	18	23.90	3.51
Potamogeton	30	28.85	4.40
Potamogeton	30	25.40	2.27
Potamogeton	32	30.73	3.40
Vallisneria	10	4.79	1.20
Vallisneria	11	2.55	0.69
Vallisneria	11	2.32	0.60
Vallisneria	18	7.87	1.43
Vallisneria	18	5.84	0.95
Vallisneria	20	7.85	2.36
Vallisneria	25	14.19	1.59
Vallisneria	30	4.91	0.88
Vallisneria	32	4.77	0.56
Vallisneria	44	19.20	4.14
Vallisneria	45	12.00	2.15
Vallisneria	46	13.16	3.32
Vallisneria	63	16.72	4.89

Plant Dry-Weight Measurement

Dry weight of each plant sample was determined following the sorting and cleaning of the plant mass. Samples that were to be stored for an extended period of time were frozen until analyzed. Each sample was independently thawed in a bucket of water and gently agitated to loosen and remove invertebrates, sediments, and detritus. The sample was then sorted into the genus types. Leaves and stems were separated from the root mass for each genus. The sample was dried at room temperature for at least 48 hours. Roots were labeled for each genus and placed into sealed plastic bags. Stems and leaves were also labeled according to genus and placed into separate sealed plastic bags.

The specimens were transported to the U.S. Geological Servey's laboratory in New Jersey for analyses. Aluminum drying containers were prepared from aluminum foil. These containers were etched with a label and dried in a VWR drying oven at an average temperature of 105° C for a minimum of one and one-half hours. They were then transferred to a desiccator for 30 minutes or until they cooled to room temperature. Each aluminum container was then weighed on a Mettler scale that had a precision of 0.1 milligram.

Each plant sample was removed from its plastic bag and wrapped in the appropriate aluminum foil container for drying. Following the same steps as those used in the aluminum container preparations, the plant specimens were dried and weighed. The aluminum container weight was then subtracted from this combined plant and aluminum weight to determine the weight attributed to only the plant. The mass represented the mass per square foot (grams/ft^2) for each sample. Following weighing, the samples were resealed in the appropriate plastic bags for storage.

Biomass Determination

The dry weight (grams/ft^2) for each sample was then compared to the measured average plant length to get linear relationships for both root mass and stem and leaf mass to various plant lengths. Using the following equation, this relationship was then extrapolated to the entire river reach to determine the total mass attributed to each plant genus.

$$\mathbf{M_{pg} = \sum [A_{pg}P_{pg}(L_{pg}D)]}$$

Where,

$\mathbf{M_{pg}}$ = the total mass (gram) of a specific plant genus within the study reach of the Delaware River;

$\mathbf{A_{pg}}$ = the areal extent (ft^2) of the specific plant genus within the individual plant bed;

$\mathbf{P_{pg}}$ = the percent coverage [/100] of a specific plant genus within the plant bed;

$\mathbf{L_{pg}}$ = the average length (ft) of the plant genus within the plant bed; and

D = biomass density ($gram/ft/ft^2$)

= [the dry mass of specific plant genus] / [the average length of specific plant genus] / [square foot of sample of specific plant genus].

Appendix B presents the genus-specific biomass data.

RESULTS

Plant-bed Area Delineation

The use of a canoe-mounted GPS provided a very efficient and accurate method of mapping the plant-bed locations and areal coverages. Occasionally, the GPS would not have adequate satellite positions to obtain accurate locational data. When this would occur, the GPS would not record position data until the satellites were in an orientation that provided a Position Dilution of Precision (PDOP) of less than or equal to 4.0. In most cases, this time frame was less than 10 minutes until the GPS was again operational. Reasons for inadequate satellite positions include tree canopy or mountains that block the satellite signals; and/or satellites grouped too closely together; and/or satellites too near the horizon. However, the width of the Delaware River usually provided ample openness for receiving signals from good satellite orientations.

Dominant Aquatic Plants

The most common rooted aquatic plants observed during this study were Elodea, Vallisneria, and Potamogeton. These were the same plant genera that were dominant during the 1989 study (Kratzer, 1990) and were also identified as dominant within the study reach by The Nature Conservancy (1994). The Elodea (waterweed) species were difficult to identify individually during this study, most of the specimens resembled E. canadensis. The Potamogeton (pondweed) genus was dominated by P. crispus and P. perfoliatus. Vallisneria americana (known as water celery, wild celery, or eel-grass) was the third dominant plant type. Heteranthera dubia (water-stargrass), a macrophyte; and Cladophora, a macro-algae, were found infrequently throughout the study reach in small masses. Plant identifications were performed using the Haslam (1978), the Cook (1990), and The Nature Conservancy (1994) taxonomic keys. Large sections of the river reach were populated with periphyton assemblages on the rocky substrates.

The study results show that good relationships exist between average plant length and average water depth, and average plant length and dry plant mass.

Plant Biomass

Average water depth and average plant length for each genera showed good correlation as illustrated in **Figures 8 to 10** for square foot samples. By extrapolation, the regression equation in **Figure 8** suggests that Elodea prefers to inhabit channel sections with water depths greater

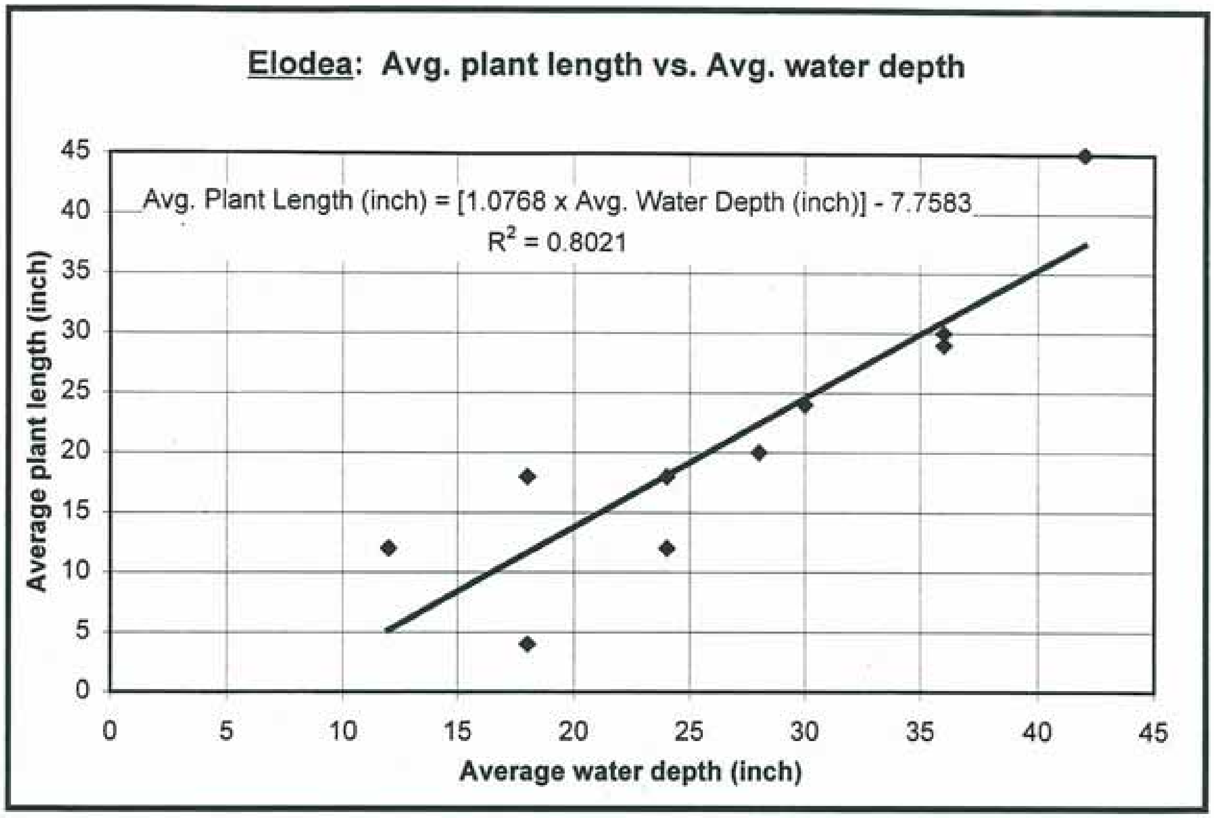

Figure 8. Average plant length versus average water depth from a square-foot sample for Elodea.

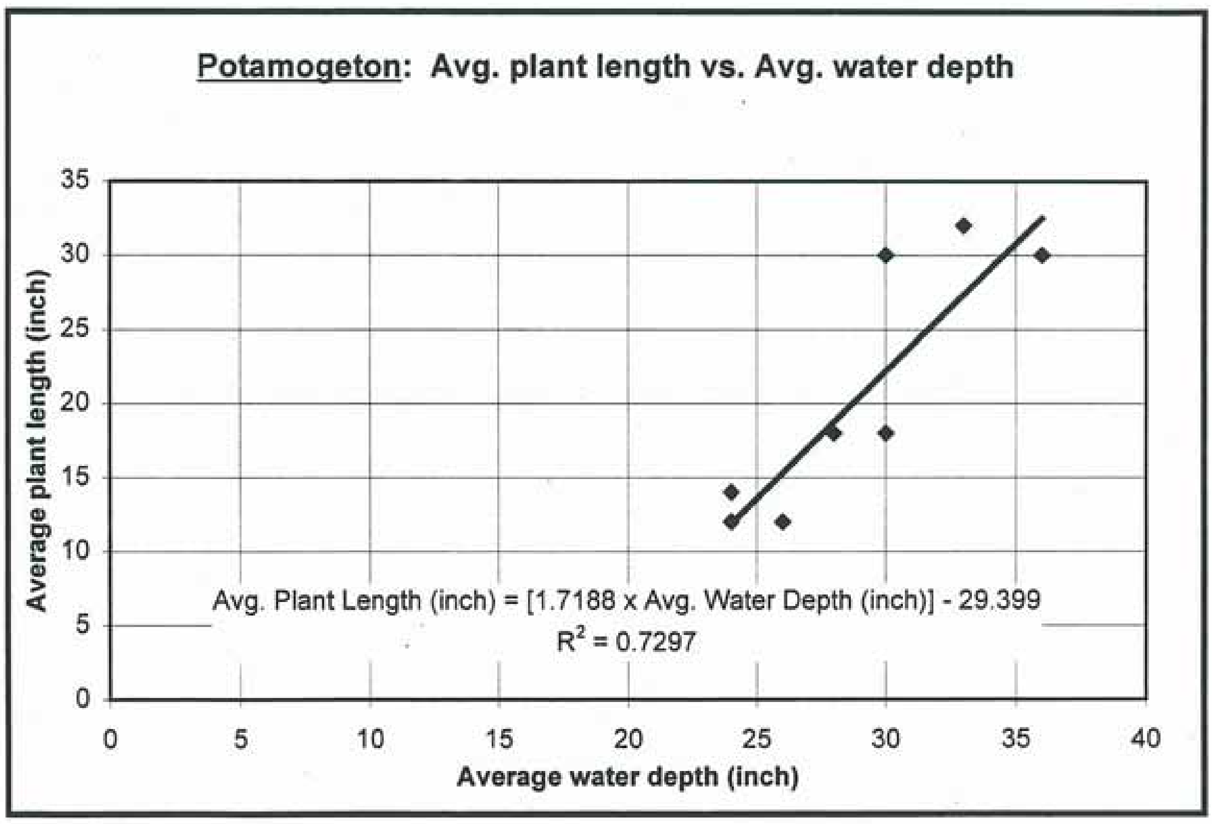

Figure 9. Average plant length versus average water depth from a square-foot sample for Potamogeton.

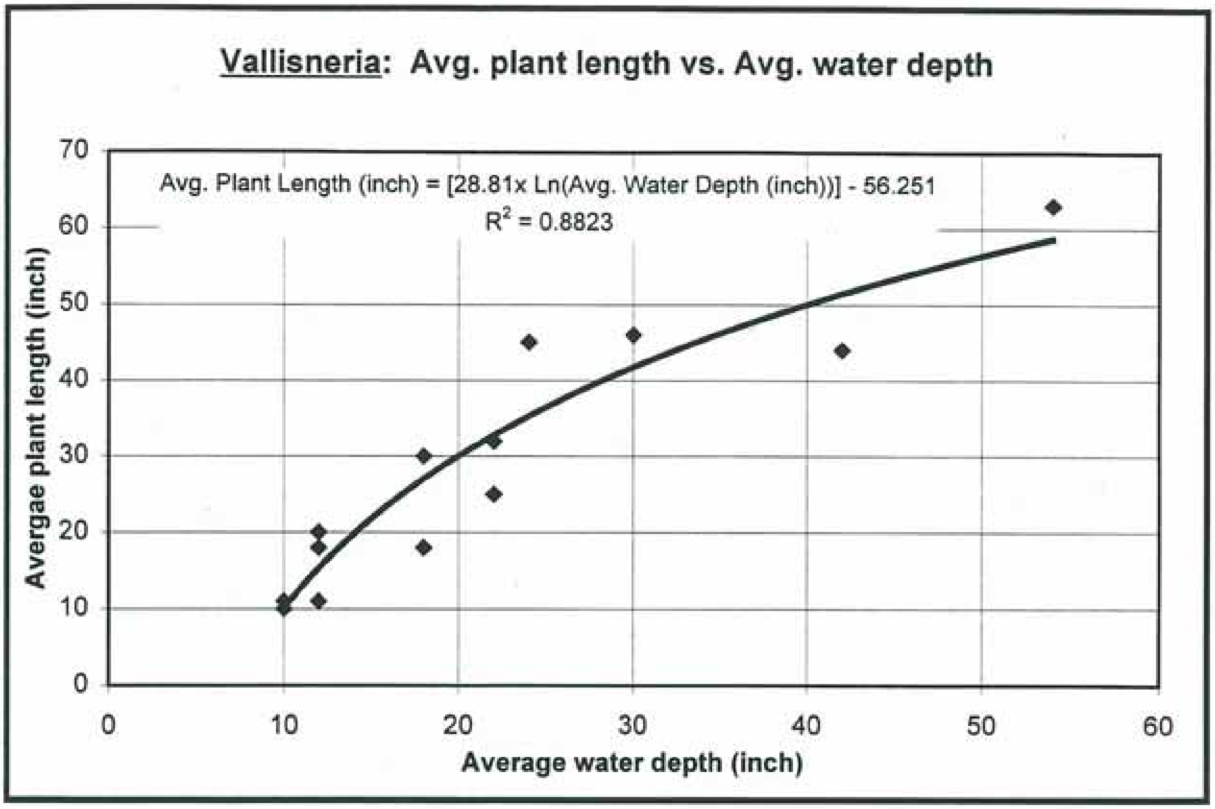

Figure 10. Average plant length versus average water depth from a square-foot sample for Vallisneria.

than 7 inches. The plant length increased approximately 1.1 inches for every additional 1 inch increase in water depth. The average length of Elodea and the average water depths for each plant bed ranged from 4 to 45 inches and 12 to 42 inches, respectively. **Figure 9** suggests that Potamogeton seems to prefer water depths of more than 17 inches. Average plant length ranged from 12 to 32 inches and average water depth ranged from 24 to 36 inches. Potamogeton obtains longer lengths per unit increase in average water depth than Elodea and Vallisneria. Vallisneria, **Figure 10**, also preferred water depths greater than 7 inches and increased logarithmically in length for increases in water depth. Average plant length ranged from 10 to 59 inches and average water depth ranged from 10 to 54 inches. Vallisneria closely parallels Elodea in the rate of average plant length increase per unit increase in average water depth up to a water depth of approximately 30 inches. In average water depths of greater than 30 inches, Elodea acquires a more rapid increase in average plant length than Vallisneria.

Water depths during the biomass collection on August 14, 15, and 25, 1997, were approximately 5 to 6 inches deeper than the seasonal low flow as measured at the U.S. Geological Survey's stream flow gage at Montague, N.J.. This may have influenced the determination of the minimum water level for growth.

The relationships between dry-weight biomass (gram) and average plant length (inch) for each genus are illustrated in **Figures 11 to 13**. Even though the regression functions do not include a zero intercept, the plant mass must intercept the average plant length at zero. All genera showed a good linear correlation between the shoot mass and the average plant length. Plant shoots include both the stems and leaves. Root mass showed good correlation to average plant length for Vallisneria. Although there exists a similar trend with the Elodea and Potamogeton root data, the coefficient of determination (R^2) indicates more variability in the data. Since Elodea relies less on roots for nutrient uptake, the variability of root mass with average plant length is not surprising. **Figure 11** shows that the Elodea data had an outlier that was approximately 65 percent greater than the regression estimate for shoot dry weight at an average plant length of 18 inches. **Figure 11a** illustrates the same data without the outlier. Potamogeton, however, relies more on roots for nutrient uptake. More data may have presented a better relationship. Potamogeton had the greatest increase in dry mass per unit increase in average plant length for both shoot and root samples (see **Figure 12**).

Good relationships existed between the root-to-shoot (R/S) biomass ratio and the plant length for each plant genus (see **Figures 14 to 16**). Barko and Smart (1986) and Barko et.al. (1991) found that plants growing in infertile (low nutrient) sediments had a high root-to-shoot ratio. The plants would produce more roots to provide more surface area for uptake of the limited nutrient supply. Data from the current study show that R/S ratios are also dependent on the plant length. Elodea and Potamogeton data present a decreasing linear relationship between the R/S ratio and average plant length with minimum root biomass approaching 2.5 and 9 percent of the shoot biomass and maximum root biomass approaching 6 and 20 percent, respectively. Root-to-shoot ranges reported by Fleckenstein (1994) for P. crispus and E. canadensis, inhabiting the Upper Delaware River near Callicoon, N.Y. did not compare favorably to the 1997 study for Potamogeton. Fleckenstein found that Potamogeton had R/S ratios from 16 to 143 percent. However, Elodea, with an R/S of 10 to 16 percent, exhibited a better association to the 1997 study. Differences in the R/S ranges for these genera may be attributed to changes in plant

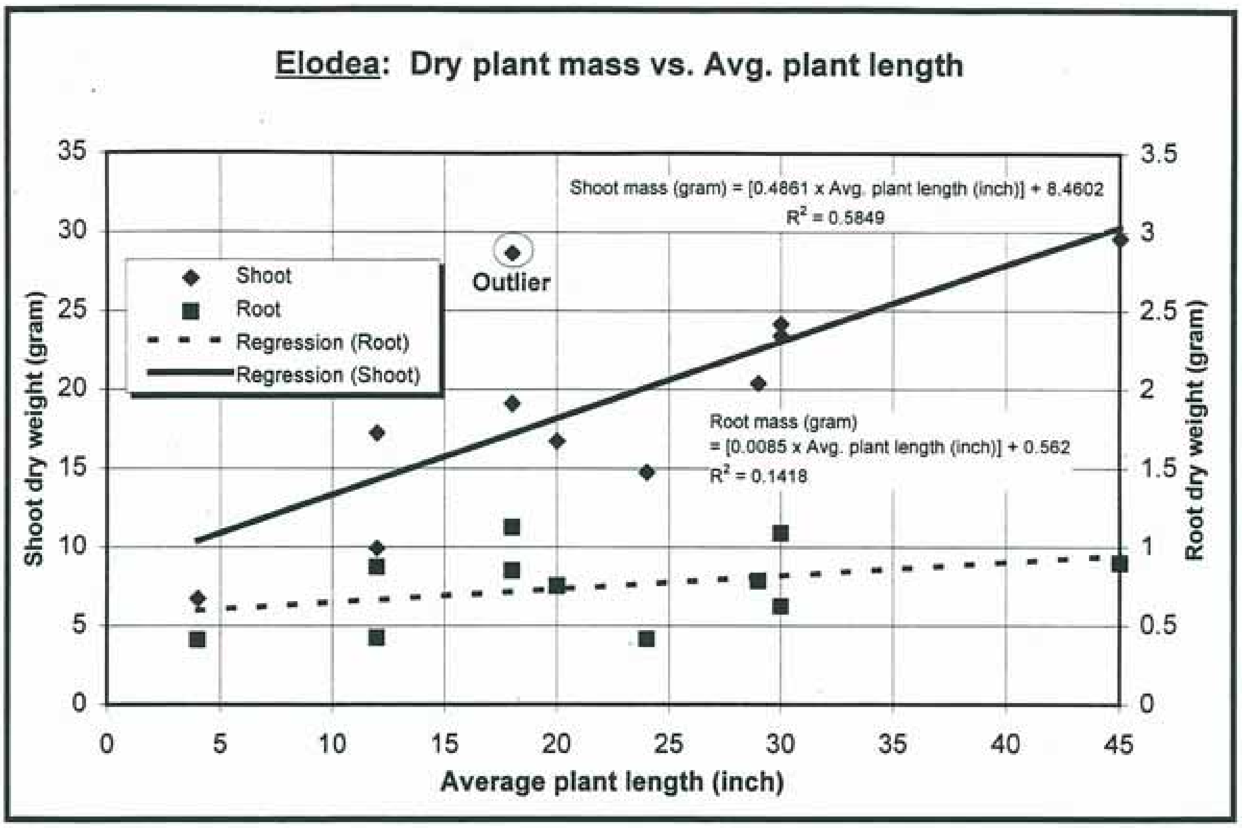

Figure 11. Dry shoot and root mass versus average plant length from a square-foot sample for Elodea.

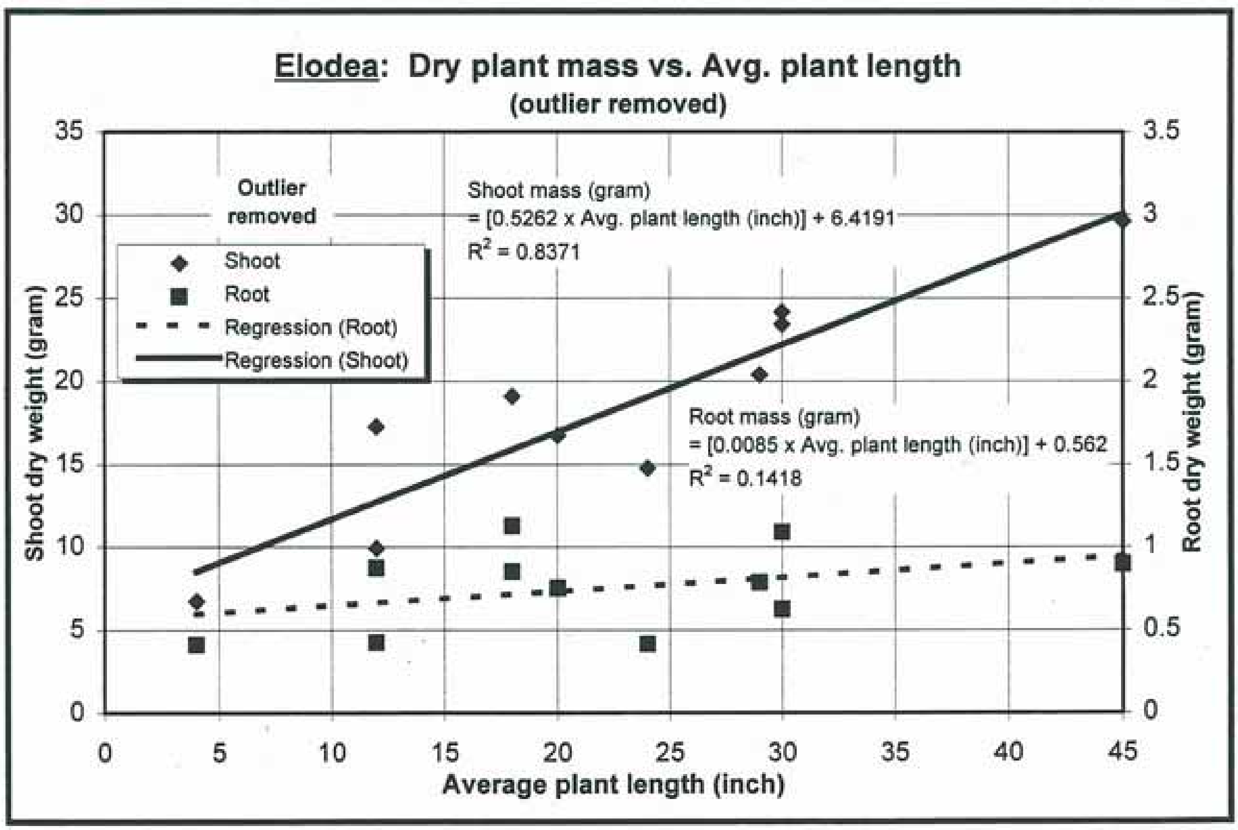

Figure 11a. Dry shoot and root mass versus average plant length from a square-foot sample for Elodea (outlier removed).

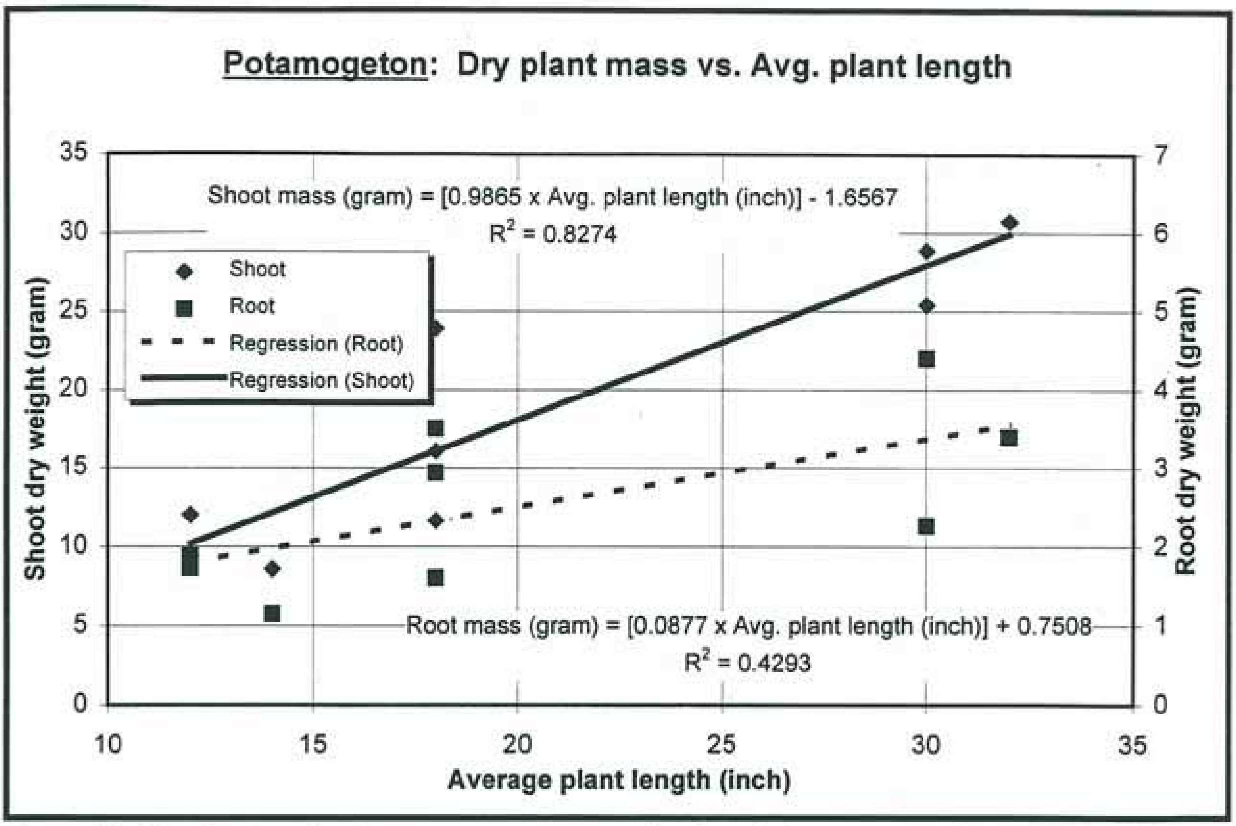

Figure 12. Dry shoot and root mass versus average plant length from a square-foot sample for Potamogeton.

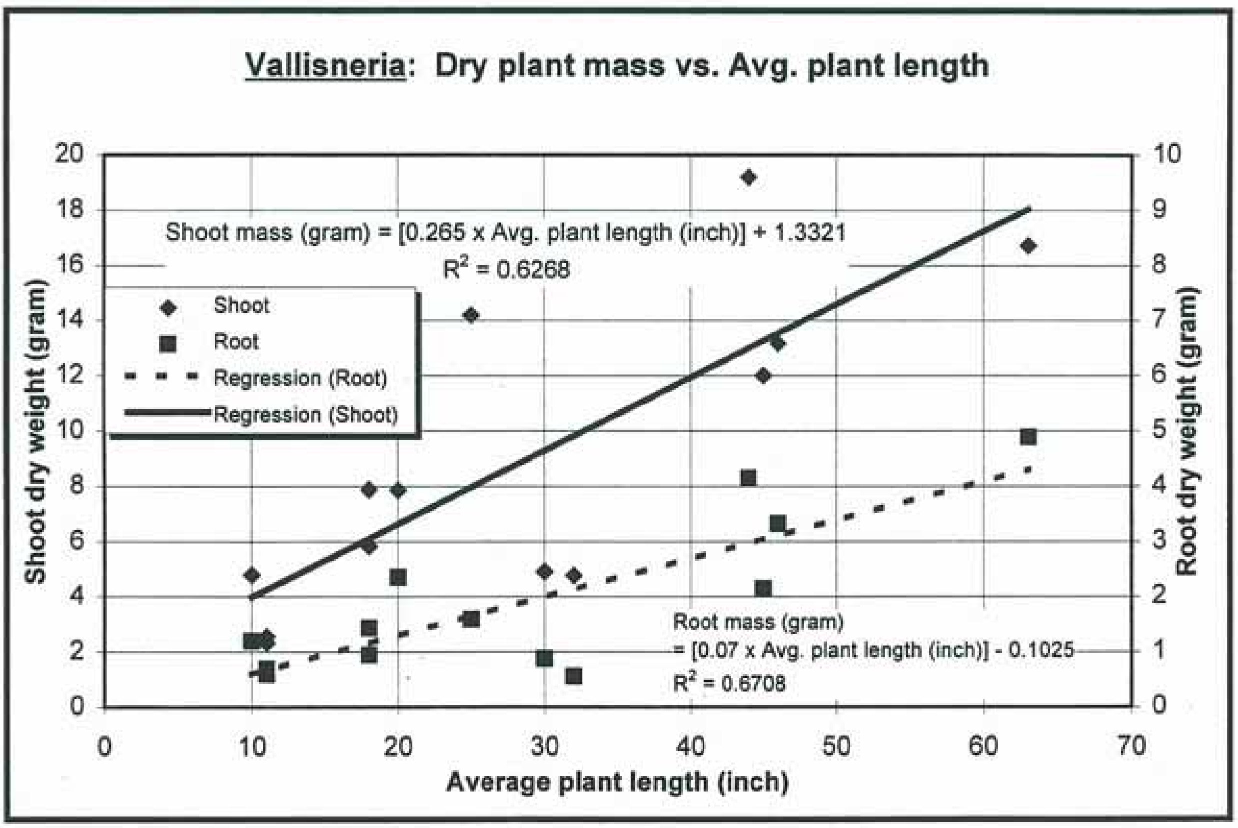

Figure 13. Dry shoot and root mass versus average plant length from a square-foot sample for Vallisneria.

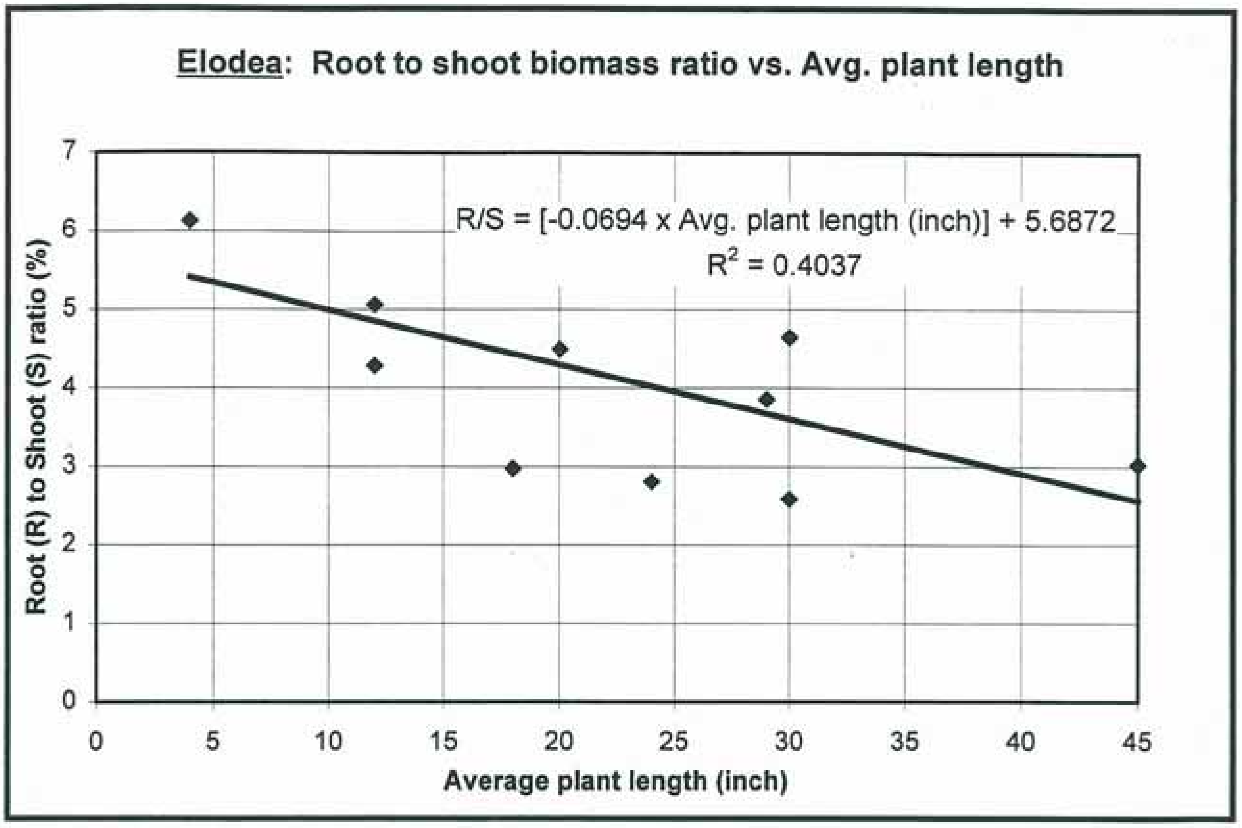

Figure 14. Root to shoot biomass ratio versus average plant length from a square-foot sample for Elodea.

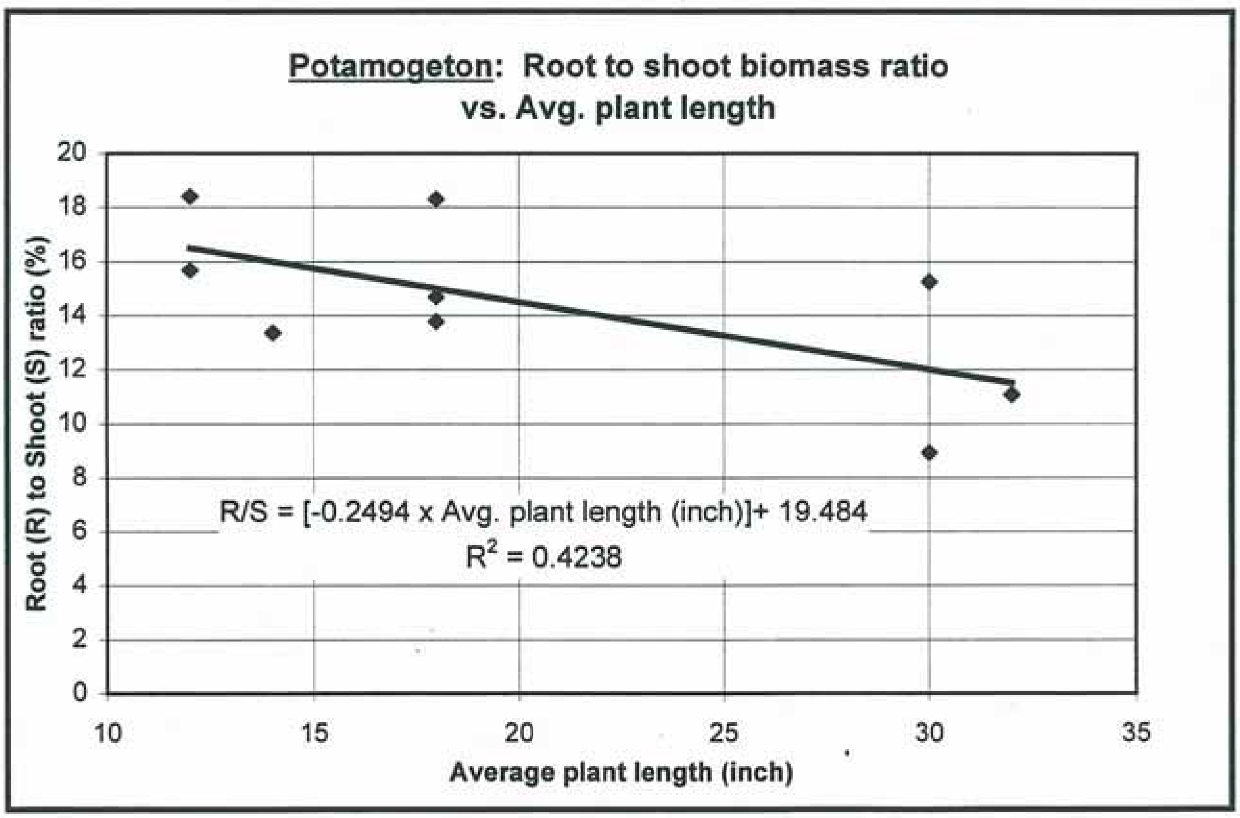

Figure 15. Root to shoot biomass ratio versus average plant length from a square-foot sample for Potamogeton.

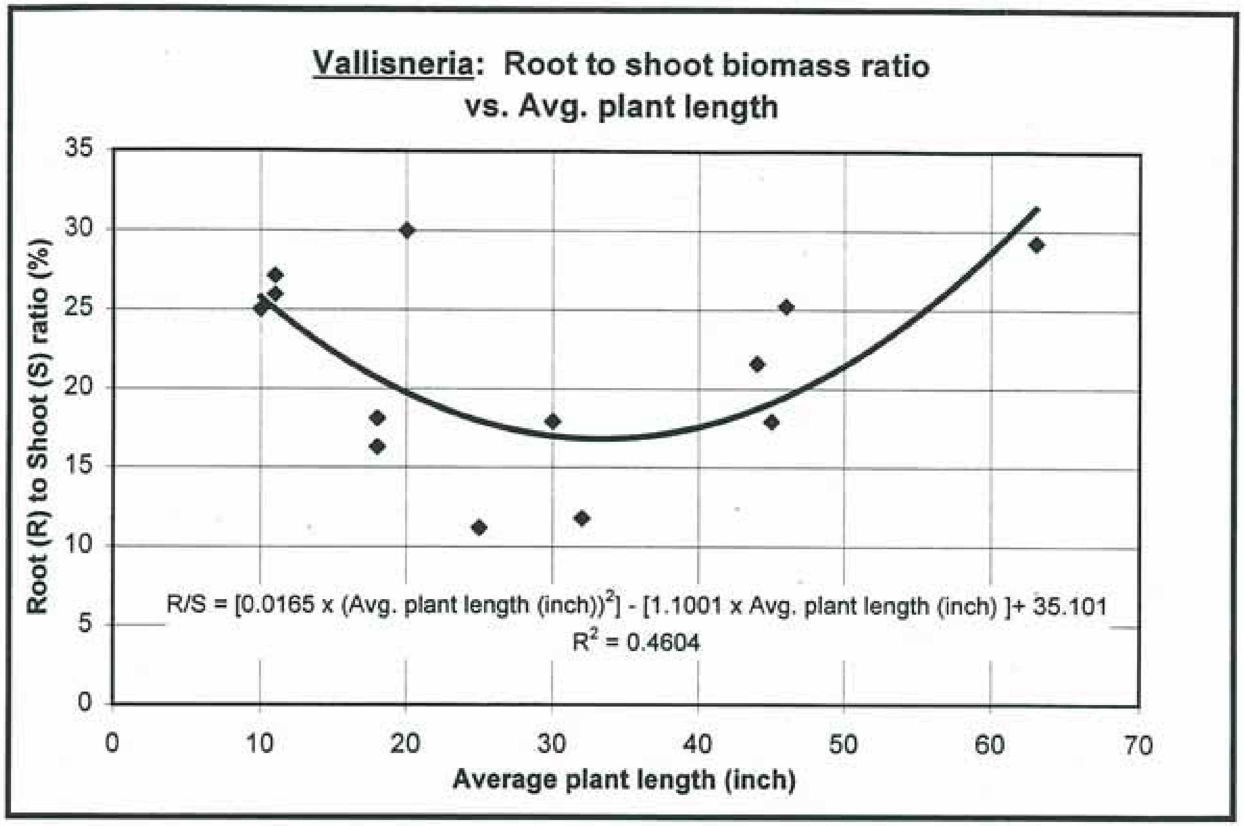

Figure 16. Root to shoot biomass ratio versus average plant length from a square-foot sample for Vallisneria.

morphology (time of sample collection) during the growing season, or to differences in sediment nutrient levels. Higher velocities, associated with higher flows, can alter the R/S ratio by stripping off leaves and stems. Macrophytes can also be uprooted by higher flows, thus decreasing the plant-bed densities of plants with low R/S ratios. However, samples collected during the 1997 study did not show any apparent changes to the plants' normal morphology. Flow records for the Port Jervis, N.Y. and the Montague, N.J. stream gages did not show any abnormalities in the seasonal flow patterns for either the 1989 or the 1997 studies.

Vallisneria displayed a polynomial relationship between the R/S ratio and average plant length with maximum root biomass approaching 30 percent of the shoot biomass (see **Figure 16**). In this case, the relationship decreased to a minimum near an average plant length of approximately 32 inches and, from there, increased to an average plant length of at least 63 inches.

Comparison to the 1989 Study

A similar macrophyte biomass study was carried out on August 16 and 17, 1989 by the Delaware River Basin Commission in cooperation with the Delaware Water Gap National Recreation Area unit of the National Park Service (Kratzer, 1990). The 1989 study measured the total biomass of the most dominant rooted aquatic plants: Potamogeton, Vallisneria, and Elodea. The study was performed in a 5.3 mile reach of the Delaware River from the Delaware Valley High School (river mile 251.28) to the route 206 bridge (river mile 246.00). The study reach was divided into 4 subreaches based on observable landmarks within the river corridor. The same Delaware River subreaches that were used for the 1989 study were again used in the 1997 study (subreaches 3 thru 6). The subreaches were based on observable landmarks within the river corridor.

Biomass

Table 3 presents the results from the 1989 and the 1997 studies for dry weight biomass (kilograms, kg) and plant bed area (ft^2) per subreach. The 1989 aquatic macrophyte biomass study contained subreaches 3 thru 6 of the present study.

The 1989 study used a plant bed delineating scheme that was similar to that used in the current study. However, the geographic location of plant beds was based on channel and overbank landmarks. Many times this scheme presented problems due to a lack of landmarks. Plant bed areas were determined by marking the outer boundary with floats and were then located in the channel by using geographic landmarks on U.S. Geological Survey topographic maps. The topographic maps were enlarged, via a copy machine, to facilitate the bed positioning.

Plant densities were determined per square foot for each of 3 plant genus: Elodea, Potamogeton, and Vallisneria. Densities were visually categorized into "sparse," "moderate," and "dense" and associated with an average biomass in each category for each genera. Values for "dense" Potamogeton and Vallisneria were not determined during the 1989 study due to time limitations. Since "dense" samples of Elodea were collected at a water depth of 36 inches, this depth was entered into the equation in **Figure 12** to determine the biomass density for Potamogeton, at this same depth, for subreaches 3 and 4. The associated biomass density for Potamogeton at a water

Table 3. Comparison of areal coverage and plant biomass between the 1989 study and the present study. N represents negligible amounts.

Sub-reach	Genus	Plant Bed Area (ft^2) 1997	Plant Bed Area (ft^2) 1989	1997 Plant Biomass (kg) Stem & Leaf	1997 Plant Biomass (kg) Root	1997 Plant Biomass (kg) Total	1989 Plant Biomass (kg) Total
1	Elodea	40,703	----------	809.7	31.7	841.4	-----------
	Potamogeton	6,142	----------	276.5	30.1	306.6	-----------
	Vallisneria	35,351	----------	476.7	109.9	586.6	-----------
	Total	***82,196***	----------	***1,562.9***	***171.7***	***1,734.6***	-----------
2	Elodea	6,865	----------	110.3	4.9	115.2	-----------
	Potamogeton	N	----------	N	N	N	-----------
	Vallisneria	3,685	----------	49.4	11.4	60.8	-----------
	Total	***10,550***	----------	***159.7***	***16.3***	***176.0***	-----------
3	Elodea	287	12,158	5.0	0.2	5.2	183.7
	Potamogeton	3,791	3,172	63.8	9.1	72.9	56.2
	Vallisneria	12,855	2,759	159.3	36.2	195.5	32.7
	Total	***16,933***	***18,089***	***228.1***	***45.5***	***273.6***	***272.6***
4	Elodea	9,979	43,697	129.7	6.7	136.4	557.8
	Potamogeton	1,509	7,656	104.6	10.7	115.3	36.4
	Vallisneria	22,138	14,092	320.7	74.7	395.4	99.6
	Total	***33,626***	***65,445***	***555.0***	***92.1***	***647.1***	***693.8***
5	Elodea	21,691	174,880	263.2	14.2	277.4	4,040.8
	Potamogeton	12,359	N	260.2	34.2	294.4	N
	Vallisneria	26,528	113,600	209.1	43.2	252.3	790.6
	Total	***60,578***	***288,480***	***732.5***	***91.6***	***824.1***	***4,831.4***
6	Elodea	43,879	116,640	561.4	29.2	590.6	2,695.1
	Potamogeton	N	N	N	N	N	N
	Vallisneria	129,824	80,800	1,382.8	306.3	1,689.1	554.8
	Total	***173,703***	***197,440***	***1,944.2***	***335.5***	***2,279.7***	***3,249.9***

depth of 36 inches was approximately 37.8 grams per square foot (g/ft^2). Dense beds of Vallisneria were located in water depths of approximately 36 inches during the 1989 study in subreaches 3 and 6. Therefore, this depth was entered into the equation in **Figure 13** to obtain an estimated biomass density of 13.3 g/ft^2. **Table 3** was adjusted to reflect these estimates of biomass for the 1989 study.

Figure 17 presents the differences per subreach between the total biomass of the 1997 and the 1989 studies. The 1989 study only had data from subreaches 3 thru 6 of the 1997 study. Total biomass for these subreaches was 4,024.5 kg for 1997 and 9,047.7 kg for 1989. This represents a reduction of 5,023.2 kg , or 11,076.2 pounds, dry plant mass in the 1997 study compared to the 1989 study. Subreach 3 was the only subreach to show an increase in total biomass. This increase equaled 0.4 percent (or 1 kg). Subreach 4 showed a 6.7 percent reduction, subreach 5 showed an 82.9 percent reduction, and subreach 6 showed a 29.8 percent reduction in total biomass between the two studies. In 1989, subreach 5 had an extremely dense growth of Elodea approximately ¼ mile upstream of the Vandermark Creek confluence. The plants were emergent in an average depth of 5 feet and the bed spanned the entire width of channel for a length of approximately ¼ mile. This plant bed has not been apparent since the 1989 study and was not present during the 1997 study.

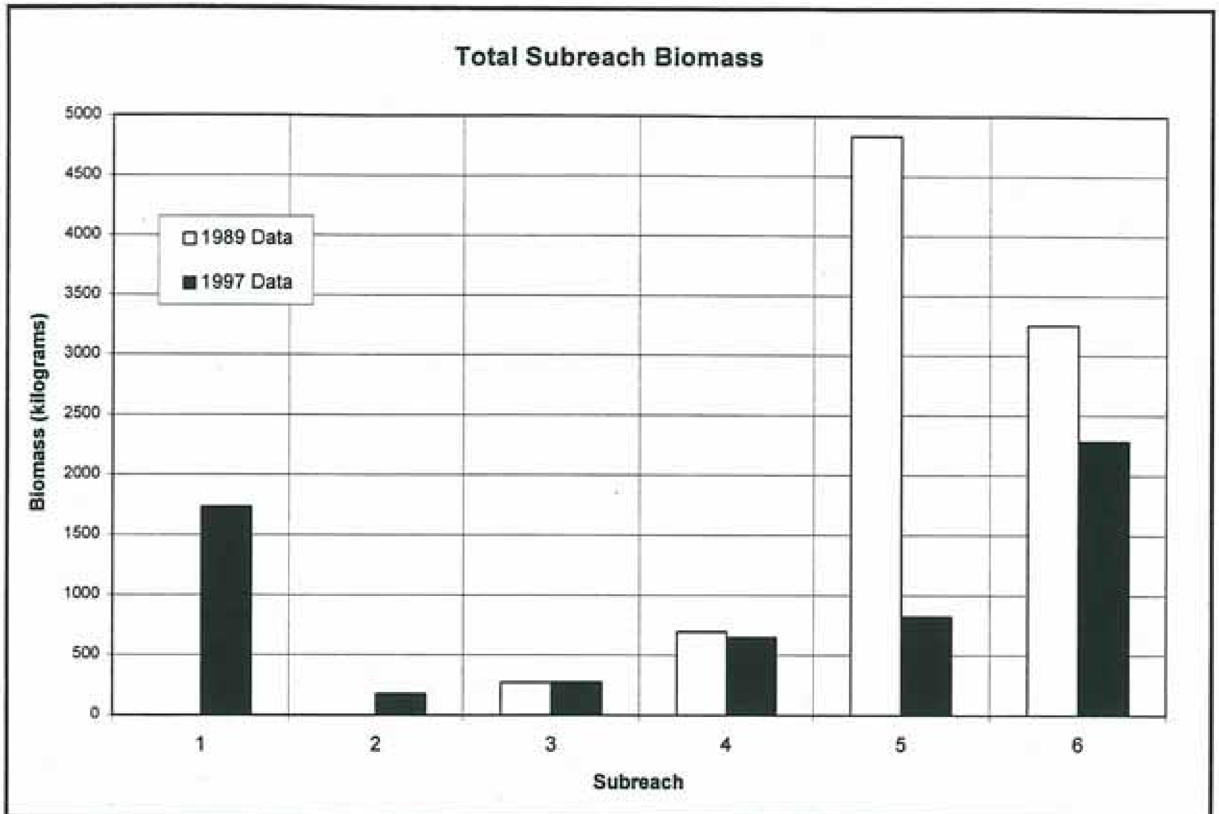

Figure 17. Total biomass comparison per subreach for the 1989 and the 1997 studies.

The main density differences in biomass between the 1997 and the 1989 studies occurred in subreaches 5 and 6. Subreach 5 had net decreases in Elodea, Vallisneria, and Potamogeton of 93.1, 68.1, and 100 percent, respectively. Subreach 6 had a net decrease in Elodea of 78.1 percent and a net increase in Vallisneria of 129.5 percent. Potamogeton was not observed in significant amounts within subreach 6 during either study.

Water Quality

Although channel substrates, flow, directed reservoir releases, water clarity, precipitation, and the exposure to solar radiation were comparable for both studies, the concentration of ammonia plus ammonium (NH_3+NH_4 as N) was greater in this section of the Delaware River during the 1989 study (Kratzer, 1990). A special water-column and sediment pore-water study was performed in 1989 at 5 sites on the Delaware River from the northern boundary (river mile 249.78) of the Delaware Water Gap National Recreation Area (DWGNRA) to Kittatinny Access (river mile 211.58). Water-column data from this study showed a nitrite plus nitrate (NO_2+NO_3 as N) concentration of 0.29 mg/l and an NH_3+NH_4 as N concentration of 0.11 mg/l at the northern DWGNRA boundary. Water-column data collected at Milford Access (river mile 246.25), during this same study, showed 0.23 mg/l NO_2+NO_3 as N and 0.65 mg/l NH_3+NH_4 as N. The water-column concentration for NH_3+NH_4 as N at the Milford Access site was more than an order of magnitude greater than that observed during the 1997 study. Water-column concentrations of total phosphate (PO_4 as P) did not show appreciable differences between the studies. Sediment pore-water, sampled at the Milford Access site during the 1989 study, showed 0.22 mg/l of total phosphorus, 0.09 mg/l of total ortho-phosphate, 0.69 mg/l of NO_2+NO_3 as N, and 0.73 mg/l of NH_3+NH_4 as N. Except for NH_3+NH_4 as N, the Milford Access site had the greatest concentration of sediment pore-water nutrients.

The 1989 water quality data presented an elevated loading of approximately 6,400 pounds per day (lb/day) of NH_3+NH_4 as N between the northern DWGNRA boundary and Milford Access. This loading is equivalent to a discharge flow of 10 cubic feet per second (cfs, or 6.45 million gallons per day) at an average concentration of 119 mg/l NH_3+NH_4 as N.

Nutrient data collected since the 1989 biomass study by the SRMP have not shown elevated nitrogen concentrations within the same study reach. Water-column data for 1990 thru 1997 showed maximum and average NO_2+NO_3 as N concentrations of 0.45 and approximately 0.23 mg/l, respectively. NH_3+NH_4 as N data that were collected from 1990 thru 1993 presented maximum and average concentrations of 0.08 and approximately 0.015 mg/l, respectively.

Nutrient data that were collected by the SRMP from 1990 thru 1993 were used to calibrate the QUAL2EU model for the Middle Delaware River. Results of the QUAL2EU model calibration reveal an average low-flow loading of approximately 770 lb/day of NO_2+NO_3 as N, extending from the route 209 bridge at Port Jervis, N.Y. (river mile 254.75) to just upstream of Hunt's Landing (river mile 252.55). As an example, this amount of loading is equivalent to a discharge flow of 10 cfs with a concentration of 14.3 mg/l of NO_2+NO_3 as N. Model results for the next downstream river reach, from the northern DWGNRA boundary (river mile 249.78) to just upstream of Vandermark Creek (river mile 247.4), indicate an additional average NO_2+NO_3 as N loading of 380 pounds per day. This loading is equivalent to a discharge flow of 10 cfs with a concentration of 7.0 mg/l of NO_2+NO_3 as N. Since the 1989 study, ambient concentrations of NH_3+NH_4 as N have not indicated substantial increases in loading throughout the study reach. Model calibrations were based on a Delaware River flow of 1,800 cfs at the U.S. Geological Survey's stream flow gage at Montague, N.J..

Sources of NH_3+NH_4 as N and NO_2+NO_3 as N entering the Delaware River include atmospheric deposition, malfunctioning septic systems, reservoir releases, agricultural practices, lawn fertilizers, and wastewater treatment plant discharges.

Data from the National Atmospheric Deposition Program (1998) monitoring station at Milford, PA show that monthly average values for NH_3+NH_4 as N and NO_2+NO_3 do not vary substantially between the 1989 and 1997 studies. Contributions from atmospheric NH_3+NH_4 as N averaged 0.16 mg/l and 0.17 mg/l for May thru September data during the 1989 and 1997 studies, respectively. Seasonal deposition data for NO_2+NO_3 as N averaged 0.34 mg/l for the 1989 study and 0.39 mg/l for the 1997 study.

Senior (1994) reported that NO_2+NO_3 as N concentrations in domestic wells along the Pennsylvania shore of the study reach were occasionally greater than 5 mg/l. Thirty-six percent of the tested wells had concentrations greater than 0.8 mg/l NO_2+NO_3 as N. Except for a residential development in Matamoras, PA, the homes along this section of the Delaware River have on-site septic systems.

Tributaries entering the plant biomass study reach include the Neversink River (river mile 253.62) and Vandermark Creek (river mile 247.30). Although these streams usually provide higher concentrations of nutrients to the Delaware River, no such data were available for the 1989 study. SRMP data from 1990 thru 1993 show average NH_3+NH_4 as N concentrations of 0.07 mg/l at the mouth of the Neversink River and 0.02 mg/l at the mouth of Vandermark Creek. SRMP data from 1990 thru 1997 show average NO_2+NO_3 as N concentrations of 0.45 mg/l and 1.00 mg/l for the Neversink River and Vandermark Creek, respectively. The total loading from these two streams during low-flow conditions is approximately 141 lb/day for NH_3+NH_4 as N and approximately 495 lb/day for NO_2+NO_3 as N.

Water releases from reservoirs for power generation and for maintaining prescribed base flows in the Delaware River did not contribute substantially to the nitrogen loading within the plant biomass study reach during either the 1989 or the 1997 study. Although not quantified, agricultural practices and lawn care within the study basin of the Delaware River may have provided substantial contributions to the nitrogen load.

A storm sewer near the route 209 bridge at Port Jervis, N.Y. (river mile 254.75) and 3 small wastewater treatment plant discharges also contribute to the increased nutrient loadings within the study reach. Periodically, the storm sewer produces a milky discharge for short durations during dry-weather conditions. One of the wastewater treatment plants is located in subreach 2 and the other two are located in subreach 3. The combined wastewater discharge from the storm sewer (during dry weather) and treatment plants is less than 0.5 cfs (0.32 million gallons per day). Assuming maximum NO_2+NO_3 as N and NH_3+NH_4 as N effluent concentrations of 30 mg/l, the maximum loading for each parameter is approximately 81 lb/day. This is equivalent to approximately one percent of the total NH_3+NH_4 as N loading that was present in this reach of the Delaware River during the 1989 study.

DISCUSSION

The 1989 water quality study presented NH_3+NH_4 as N concentrations that were elevated compared to the historical data for this segment of the river. If present today, the extent and duration of the problem would not have violated the existing regulations for Special Protection Waters. However, the density of aquatic plants would increase by more than 160 percent over 2.8 miles of the Delaware River (subreaches 5 and 6).

Relationships derived from the 1997 study allow estimations of average plant length, R/S ratios, and root and shoot biomass from average water depth measurements for <u>Elodea</u>, <u>Potamogeton</u>, and <u>Vallisneria</u>. These relationships are good tools to use for separating the mass of plant tissue associated with photosynthesis and the amount associated with respiration for plant productivity models.

Macrophytes and Cladophora are good indicators of nutrient, PCB, metals, and organotoxin pollution in both the water column and sediments. The bioaccumulation of these pollutants by the plant tissue provides a water quality sample that has concentrations much greater than the water column, sediments, or macroinvertebrates. Plant biomass can be easily dried and stored to develop a historical reference of contamination types, locations, and trends. Contamination references can be established temporally for a given site or spatially and temporally for multiple sites.

CONCLUSIONS AND RECOMMENDATIONS

- Global Positioning System (GPS) techniques provide a more accurate and a more efficient means of collecting plant-bed location and area data than rod or tape measuring techniques.

- The root-to-shoot (R/S) ratio is not based solely on the availability of nutrients in the sediments, but is also a function of the plant length and habitat conditions. The ratio is a good indicator of the supply of soil nutrients when plant specimens of the same genus and length are compared.

- Dense growths of macrophytes are good indicators of frequent contributions of nutrients to a waterway and should be considered as supplemental water quality criteria for the Special Protection Waters regulations.

- If nutrients (particularly nitrogen and phosphorus) are allowed to accumulate in the Delaware River, then the channel may exhibit loss of habitat, stability, and sensitive organisms due to excessive growths of aquatic plants.

- Stationary aquatic-plant productivity should be included in the modeling program(s) for Delaware River water quality to properly simulate nutrient and dissolved-oxygen budgets.

- Macrophytes, Cladophora, and other aquatic plants should be included as biological indicators for monitoring stream water quality.

- Good relationships existed between average plant length per genus and shoot and root biomass per unit bed area during the maximum-density season (usually from late July thru early September).

- Consistent plant lengths within the peak biomass season can be used for temporal and spatial comparisons of both R/S biomass densities and bioaccumulation assays.

- The study reach of the Delaware River is nitrogen limited and is therefore susceptible to extensive aquatic-plant growth at NH_3+NH_4 as N and NO_2+NO_3 as N concentrations greater than approximately 0.10 and 0.40 mg/l, respectively. Since most rooted aquatic plants can metabolize either form of nitrogen, the average concentration for maximum productivity lies between these two concentration limits.

- Subsequent investigations, using the same biomass measurement protocol, should be conducted on subreaches of the Upper and Lower Delaware River to determine the spatial extent of the relationships that were determined from this study.

- Volatile mass (ash-free dry weight) was not determined for the macrophytes during this study due to time constraints. However, the dry plant samples were stored and should be further analyzed for volatile mass. The volatile to dry weight ratio is used for calibrating plant productivity models for nutrient and oxygen dynamics.

- Subsequent investigations should be performed to determine the magnitude and extent of nitrogen supply to the Delaware River from ground water, storm-water runoff, and dischargers. The data will be used for further calibration of a rooted aquatic-plant water quality model as well as watershed models (ground and surface water). These models will provide a management tool for predicting changes to flow, water quality, and aquatic plant density from anticipated changes in discharge allocations, land use, and changes in vegetative cover.

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Appendix A

Genus-Specific Macrophyte Habitat Characteristics

Subreach 1: Rooted Aquatic Plant Data						
Map[1] Code	Genus	Total Bed Area (ft^2)	% Plant Coverage	Areal Plant Coverage (ft^2)	Substrate Type[2]	Avg. Water Depth (ft)
PAE11A	Elodea	203	60	122	cobble, sand	1.5
PAE1C	Elodea	408	50	204	cobble, sand	2.5
PAE1.53	Elodea	204	80	163	cobble, silt	2.0
PAE1.54B	Elodea	510	70	357	cobble, silt	2.0
PAE12A	Elodea	272	70	190	cobble, silt	2.0
NYE1.5A	Elodea	714	70	500	sand	2.0
PAE2C	Elodea	578	90	520	cobble, silt	2.0
PAE2.5D	Elodea	510	75	383	cobble, silt	2.5
PAE2E	Elodea	714	60	428	cobble, silt	3.0
PAE2.5G	Elodea	612	40	245	cobble, sand, silt	4.0
PAE2.75F	Elodea	646	60	388	cobble, silt	3.5
PAE1.52	Elodea	4,690	40	1,876	cobble, sand	2.5
PAE1.5H	Elodea	2,699	50	1,350	cobble, sand	4.0
PAVE3.52.5	Elodea	5,815	50	2,907	cobble, sand	3.0
PAE3	Elodea	2,100	80	1,680	cobble, sand	3.5
PAVE32.5	Elodea	768	60	461	cobble, sand	2.5
PAE2	Elodea	2,048	100	2,048	cobble, sand	3.0
PAE1.5	Elodea	2,016	50	1,008	cobble, sand	5.0
NYE1C	Elodea	1,176	25	294	sand	4.5
NYE2B	Elodea	1,134	75	851	sand	2.5
PAE1.51B	Elodea	416	70	291	cobble, sand	2.0
PAE1.5	Elodea	2,016	40	2,395	cobble, sand	2.0
PAVE3.52.5	Elodea	37,270	30	11,181	cobble, sand	3.0
PAVEP424	Elodea	27,223	30	8,167	cobble, sand	2.5
NJE2.5	Elodea	2,475	10	248	cobble	3.5
NJVEP3.53.53.5	Elodea	4,128	16	660	cobble, sand	2.5
NJE1.5	Elodea	1,275	70	893	cobble	2.5
NJE2A	Elodea	1,275	70	893	cobble	2.5
PAVEP424	Potamogeton	27,223	20	5,445	cobble, sand	2.5
NJVEP3.53.53.5	Potamogeton	4,128	16	660	cobble, sand	2.5
NJVP3.53.5	Potamogeton	732	5	37	cobble	2.5
PAVE3.52.5	Vallisneria	37,270	50	2,907	cobble, sand	3.0
PAV4.5	Vallisneria	3,640	40	1,456	cobble, sand	3.5
PAVE32.5	Vallisneria	768	40	307	cobble, sand	2.5
PAV2.5A	Vallisneria	798	15	120	cobble, silt	1.5
PAV3.5	Vallisneria	798	20	160	cobble, silt	2.5
PAV4.25B	Vallisneria	646	80	517	cobble, silt	3.0
PAV5C	Vallisneria	1,734	85	1,474	cobble, silt	4.0

[1] Map Codes are presented in the attributes table for the plant-bed GIS data.

[2] Adapted from the grade scale developed by the American Geophysical Union, Subcommittee on Sediment Terminology (Chow, 1964). Substrate type is based on sediment particle size: boulder, > 12 inches; cobble, 2.5 to 12 inches; gravel, 0.08 to < 2.5 inches; sand, 0.002 to < 0.08 inches; and silt, < 0.002 inches. All measurements were visual estimates of this grade scale. Substrates are listed in order of dominance for each plant bed.

PAVE3.52.5	Vallisneria	37,270	30	11,181	cobble, sand	3.0
NJV47	Vallisneria	2,528	60	1,517	cobble, silt	3.0
PAVEP424	Vallisneria	27,223	50	13,612	cobble, sand	2.5
NJVEP3.53.53.5	Vallisneria	4,128	48	1,981	cobble, sand	2.5
NJV4	Vallisneria	823	10	82	cobble	3.5
NJVP3.53.5	Vallisneria	732	5	37	cobble	2.5

Subreach 2: Rooted Aquatic Plant Data						
Map Code	Genus	Total Bed Area (ft^2)	% Plant Coverage	Areal Plant Coverage (ft^2)	Substrate Type	Avg. Water Depth (ft)
NJE1.5B	Elodea	1,210	90	1,089	cobble	2.0
NJE1C	Elodea	1,570	60	942	cobble	2.0
NJEV45D	Elodea	640	38	240	cobble	4.0
NJEV3.54.5F	Elodea	954	25	239	cobble	3.0
PAE1	Elodea	4,080	20	816	cobble, boulder	1.5
PAE1.5	Elodea	11,798	30	3,539	boulder	2.5
NJEV45D	Vallisneria	640	38	240	cobble	4.0
NJEV3.54.5F	Vallisneria	954	25	239	cobble	3.0
NJV4E	Vallisneria	362	60	217	cobble	3.0
NJV4G	Vallisneria	3,770	60	2,262	cobble	3.0
PAV2.59	Vallisneria	2,424	30	727	boulder	1.5

Subreach 3: Rooted Aquatic Plant Data						
Map Code	Genus	Total Bed Area (ft^2)	% Plant Coverage	Areal Plant Coverage (ft^2)	Substrate Type	Avg. Water Depth (ft)
NJE1.54	Elodea	349	15	52	cobble, boulder	2.5
NJE1.53	Elodea	2,652	10	265	cobble, boulder	2.5
PAVP21.5G	Potamogeton	2,312	35	809	cobble, sand	1.5
PAP1.5A	Potamogeton	1,330	100	1,330	cobble, sand	1.5
PAP1.5B	Potamogeton	816	90	734	cobble, sand	2.0
PAVP3.53	Potamogeton	850	18	153	cobble	2.5
PAP1.5	Potamogeton	850	90	765	cobble	1.5
PAV4	Vallisneria	16,649	20	3,330	cobble, boulder	3.5
PAV3.5	Vallisneria	2,352	10	235	cobble, boulder	3.0
PAV3	Vallisneria	3,024	30	907	cobble	3.5
PAVP21.5G	Vallisneria	2,312	35	809	cobble, sand	1.5
PAV3F	Vallisneria	1,156	50	578	cobble, sand	2.0
PAV3.5D	Vallisneria	3,264	75	2,448	cobble, sand	2.5
PAV3.5C	Vallisneria	3,468	50	1,734	cobble, sand	2.0
PAV3.5E	Vallisneria	2,890	85	2,457	cobble, sand	2.5
PAVP3.53	Vallisneria	850	42	357	cobble	2.5

Subreach 4: Rooted Aquatic Plant Data						
Map Code	Genus	Total Bed Area (ft^2)	% Plant Coverage	Areal Plant Coverage (ft^2)	Substrate Type	Avg. Water Depth (ft)
NJE1A	Elodea	33,378	15	5,007	cobble, sand	2.5
PAE1.5	Elodea	1,257	20	251	cobble, boulder	2.0
NJVEP5.51.56E	Elodea	15,086	10	1,509	cobble, sand	4.5
NJVE3.51D	Elodea	12,767	18	2,298	cobble, boulder	3.5
PAE.5	Elodea	6,936	10	694	cobble, boulder	2.5
NJVE2.5.5	Elodea	4,400	5	220	cobble	2.0
NJVEP5.51.56E	Potamogeton	15,086	10	1,509	cobble, sand	4.5
NJV3C	Vallisneria	2,408	75	1,806	sand, silt	2.0
NJV2B	Vallisneria	12,684	10	1,268	cobble, sand	1.5
NJVEP5.51.56E	Vallisneria	15,086	40	6,035	cobble, sand	4.5
NJVE3.51D	Vallisneria	12,767	42	5,362	cobble, boulder	3.5
NJVE2.5.5	Vallisneria	4,400	20	880	cobble	2.0
NJV7	Vallisneria	6,358	90	5,722	cobble, boulder	3.5
NJV3.5	Vallisneria	2,130	50	1,065	cobble, boulder	3.0

Subreach 5: Rooted Aquatic Plant Data						
Map Code	Genus	Total Bed Area (ft^2)	% Plant Coverage	Areal Plant Coverage (ft^2)	Substrate Type	Avg. Water Depth (ft)
NJE.5	Elodea	3,162	30	949	cobble, silt, sand	1.0
NJE.5	Elodea	14,573	10	1,457	cobble, silt, sand	2.0
NJE1	Elodea	7,259	30	2,178	silt	3.0
PAE.5	Elodea	17,012	10	1,701	cobble, silt, sand	2.5
NJE13	Elodea	7,335	20	1,467	boulder, cobble, sand	3.0
NJPVE2.52.51	Elodea	23,463	2	387	cobble, sand	3.0
NJE14	Elodea	43,394	20	8,679	cobble, sand, silt	3.5
NJE15	Elodea	24,366	20	4,873	boulder, cobble, silt	5.0
MidP1A	Potamogeton	17,464	10	1,746	cobble, sand	2.0
MidP3.5B	Potamogeton	900	80	720	cobble, sand	1.5
NJPV34	Potamogeton	6,358	10	639	cobble, silt, sand	4.0
NJPVE2.52.51	Potamogeton	23,463	2	387	cobble, sand	3.0
PAP2.51	Potamogeton	39,296	10	3,930	boulder, cobble, sand	1.5
NJP1	Potamogeton	13,430	10	1,343	cobble, sand	1.5
NJP2	Potamogeton	10,268	35	3,594	cobble, sand	1.5
NJV4	Vallisneria	10,995	40	4,398	cobble, boulder	3.5
NJPV34	Vallisneria	6,358	5	315	cobble, silt, sand	4.0
PAV32	Vallisneria	8,970	20	1,794	boulder, cobble, sand	3.0
NJPVE2.52.51	Vallisneria	23,463	2	387	cobble, sand	3.0
NJV1.51	Vallisneria	65,448	30	19,634	boulder, cobble, sand	2.5

Subreach 6: Rooted Aquatic Plant Data						
Map Code	Genus	Total Bed Area (ft^2)	% Plant Coverage	Areal Plant Coverage (ft^2)	Substrate Type	Avg. Water Depth (ft)
NJE16	Elodea	37,836	60	22,702	boulder, cobble, silt	5.0
NJE17	Elodea	47,354	35	16,574	cobble, sand, silt	2.5
PAE2	Elodea	2,818	15	423	sand, cobble	5.5
PAE1	Elodea	6,800	50	3,400	sand, cobble	3.5
PAE1	Elodea	7,800	10	780	sand, cobble	2.0
MidV3.5	Vallisneria	1,785	30	536	cobble, sand, silt	6.0
NJPAV31	Vallisneria	149,088	50	74,544	cobble, sand, silt	3.5
MidV31	Vallisneria	103,326	35	36,164	bedrock, cobble, sand	3.5
PAV2.52	Vallisneria	46,450	40	18,580	sand, cobble	2.0

Appendix B

Genus-Specific Macrophyte Biomass Data

Subreach 1: Rooted Aquatic Plant Data					
Map Code	Genus	Avg. Plant Length (ft)	Areal Plant Coverage (ft²)	Leaf & Stem Mass (gram)	Root Mass (gram)
PAE11A	Elodea	1.00	122	1,551	81
PAE1C	Elodea	1.00	204	2,598	136
PAE1.53	Elodea	1.50	163	2,593	117
PAE1.54B	Elodea	1.50	357	5,673	255
PAE12A	Elodea	1.00	190	2,424	126
NYE1.5A	Elodea	1.50	500	7,942	357
PAE2C	Elodea	2.00	520	9,909	398
PAE2.5D	Elodea	2.50	383	8,494	312
PAE2E	Elodea	2.00	428	8,160	328
PAE2.5G	Elodea	2.50	245	5,436	200
PAE2.75F	Elodea	2.75	388	9,219	327
PAE1.52	Elodea	1.50	1,876	29,809	1,341
PAE1.5H	Elodea	1.50	1,350	21,445	965
PAVE3.52.5	Elodea	2.50	2,907	64,557	2,375
PAE3	Elodea	3.00	1,680	42,609	1,458
PAVE32.5	Elodea	2.50	461	10,232	376
PAE2	Elodea	2.00	2,048	39,010	1,569
PAE1.5	Elodea	1.50	1,008	16,018	721
NYE1C	Elodea	1.00	294	3,744	195
NYE2B	Elodea	2.00	851	16,200	652
PAE1.51B	Elodea	1.50	291	4,627	208
PAE1.5	Elodea	1.50	2,395	38,058	1,712
PAVE3.52.5	Elodea	2.50	11,181	248,275	9,135
PAVEP424	Elodea	2.00	8,167	155,563	6,256
NJE2.5	Elodea	2.50	248	5,496	202
NJVEP3.53.53.5	Elodea	3.50	660	18,837	607
NJE1.5	Elodea	1.50	893	14,182	638
NJE2A	Elodea	2.00	893	17,000	684
PAVEP424	Potamogeton	4.00	5,445	248,794	27,008
NJVEP3.53.53.5	Potamogeton	3.50	660	26,272	2,929
NJVP3.53.5	Potamogeton	3.50	37	1,456	162
PAVE3.52.5	Vallisneria	3.50	2,907	36,231	8,250
PAV4.5	Vallisneria	4.50	1,456	22,775	5,354
PAVE32.5	Vallisneria	3.00	307	3,340	743
PAV2.5A	Vallisneria	2.50	120	1,111	239
PAV3.5	Vallisneria	3.50	160	1,989	453
PAV4.25B	Vallisneria	4.25	517	7,673	1,792
PAV5C	Vallisneria	5.00	1,474	25,398	6,039
PAVE3.52.5	Vallisneria	3.50	11,181	139,339	31,726
NJV47	Vallisneria	4.00	1,517	21,314	4,941
PAVEP424	Vallisneria	4.00	13,612	191,272	44,340
NJVEP3.53.53.5	Vallisneria	3.50	1,981	24,693	5,622
NJV4	Vallisneria	4.00	82	1,156	268
NJVP3.53.5	Vallisneria	3.50	37	456	104

Subreach 2: Rooted Aquatic Plant Data					
Map Code	Genus	Avg. Plant Length (ft)	Areal Plant Coverage (ft^2)	Leaf & Stem Mass (gram)	Root Mass (gram)
NJE1.5B	Elodea	1.50	1,089	17,305	779
NJE1C	Elodea	1.00	942	11,995	626
NJEV45D	Elodea	4.00	240	7,602	233
NJEV3.54.5F	Elodea	3.50	239	6,802	219
PAE1	Elodea	1.00	816	10,390	542
PAE1.5	Elodea	1.50	3,539	56,244	2,531
NJEV45D	Vallisneria	5.00	240	4,136	983
NJEV3.54.5F	Vallisneria	4.50	239	3,731	877
NJV4E	Vallisneria	4.00	217	3,052	708
NJV4G	Vallisneria	4.00	2,262	31,786	7,368
PAV2.59	Vallisneria	2.50	727	6,750	1,453

Subreach 3: Rooted Aquatic Plant Data					
Map Code	Genus	Avg. Plant Length (ft)	Areal Plant Coverage (ft^2)	Leaf & Stem Mass (gram)	Root Mass (gram)
NJE1.54	Elodea	1.5	52	832	37
NJE1.53	Elodea	1.5	265	4,214	190
PAVP21.5G	Potamogeton	1.5	809	13,028	1,885
PAP1.5A	Potamogeton	1.5	1,330	21,413	3,098
PAP1.5B	Potamogeton	1.5	734	11,824	1,711
PAVP3.53	Potamogeton	3.0	153	5,180	598
PAP1.5	Potamogeton	1.5	765	12,317	1,782
PAV4	Vallisneria	4.0	3,330	46,790	10,847
PAV3.5	Vallisneria	3.5	235	2,931	667
PAV3	Vallisneria	3.0	907	9,863	2,193
PAVP21.5G	Vallisneria	2.0	809	6,224	1,276
PAV3F	Vallisneria	3.0	578	6,284	1,397
PAV3.5D	Vallisneria	3.5	2,448	30,507	6,946
PAV3.5C	Vallisneria	3.5	1,734	21,609	4,920
PAV3.5E	Vallisneria	3.5	2,457	30,613	6,970
PAVP3.53	Vallisneria	3.5	357	4,449	1,013

Subreach 4: Rooted Aquatic Plant Data					
Map Code	Genus	Avg. Plant Length (ft)	Areal Plant Coverage (ft^2)	Leaf & Stem Mass (gram)	Root Mass (gram)
NJE1A	Elodea	1.0	5,007	63,752	3,324
PAE1.5	Elodea	1.5	251	3,994	180
NJVEP5.51.56E	Elodea	1.5	1,509	23,973	1,079
NJVE3.51D	Elodea	1.0	2,298	29,261	1,526
PAE.5	Elodea	0.5	694	6,642	425
NJVE2.5.5	Elodea	0.5	220	2,107	135
NJVEP5.51.56E	Potamogeton	6.0	1,509	104,656	10,659

NJV3C	Vallisneria	3.0	1,806	19,635	4,366
NJV2B	Vallisneria	2.0	1,268	9,756	2,001
NJVEP5.51.56E	Vallisneria	5.5	6,035	113,582	27,261
NJVE3.51D	Vallisneria	3.5	5,362	66,821	15,215
NJVE2.5.5	Vallisneria	2.5	880	8,168	1,758
NJV7	Vallisneria	4.5	5,722	89,507	21,043
NJV3.5	Vallisneria	3.5	1,065	13,272	3,022

Subreach 5: Rooted Aquatic Plant Data

Map Code	Genus	Avg. Plant Length (ft)	Areal Plant Coverage (ft^2)	Leaf & Stem Mass (gram)	Root Mass (gram)
NJE.5	Elodea	0.5	949	9,084	582
NJE.5	Elodea	0.5	1,457	13,956	893
NJE1	Elodea	1.0	2,178	27,730	1,446
PAE.5	Elodea	0.5	1,701	16,291	1,043
NJE13	Elodea	1.0	1,467	18,679	974
NJPVE2.52.51	Elodea	1.0	387	4,930	257
NJE14	Elodea	1.0	8,679	110,512	5,763
NJE15	Elodea	1.0	4,873	62,052	3,236
MidP1A	Potamogeton	1.0	1,746	17,781	3,149
MidP3.5B	Potamogeton	3.5	720	28,639	3,193
NJPV34	Potamogeton	3.0	639	21,634	2,497
NJPVE2.52.51	Potamogeton	2.5	387	10,816	1,309
PAP2.51	Potamogeton	2.5	3,930	109,787	13,289
NJP1	Potamogeton	1.0	1,343	13,674	2,422
NJP2	Potamogeton	1.5	3,594	57,861	8,371
NJV4	Vallisneria	4.0	4,398	61,801	14,326
NJPV34	Vallisneria	4.0	315	4,422	1,025
PAV32	Vallisneria	3.0	1,794	19,504	4,337
NJPVE2.52.51	Vallisneria	2.5	387	3,594	773
NJV1.51	Vallisneria	1.5	19,634	119,811	22,727

Subreach 6: Rooted Aquatic Plant Data

Map Code	Genus	Avg. Plant Length (ft)	Areal Plant Coverage (ft^2)	Leaf & Stem Mass (gram)	Root Mass (gram)
NJE16	Elodea	1.0	22,702	289,073	15,074
NJE17	Elodea	1.0	16,574	211,045	11,005
PAE2	Elodea	2.0	423	8,051	324
PAE1	Elodea	1.0	3,400	43,294	2,258
PAE1	Elodea	1.0	780	9,932	518
MidV3.5	Vallisneria	3.5	536	6,674	1,520
NJPAV31	Vallisneria	3.0	74,544	810,452	180,211
MidV31	Vallisneria	3.0	36,164	393,180	87,427
PAV2.52	Vallisneria	2.5	18,580	172,461	37,114