Ecological Functions of a Created Freshwater Tidal Wetland

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A 3.1-acre freshwater tidal wetland was created in 1986 along Rancocas Creek in Burlington County, New Jersey, to partially compensate for wetland losses associated with a nearby bridge construction project. An existing upland site was graded to an elevation that provides for inundation of the created marsh during mean high tide with between 1.0 and 2.2 ft of water. Three perennial species, *Peltandra virginica*, *Sagittaria latifolia*, and *Pontederia cordata*, were planted in the created marsh in the spring of 1986. Vegetation was sampled in September 1986 and 1987. Fish and benthic invertebrates were sampled in September 1987 and August 1988. Wildlife use of the marsh was observed and recorded throughout the study period. Sediment depth was sampled in June 1988. Unplanted, volunteer vegetation has become well established throughout the wetland. The created marsh exhibits an ecosystem structure consistent with a developing freshwater tidal wetland in which the following functions are being performed: primary productivity and food chain support, fish and wildlife habitat, sediment trapping, nutrient transformation, and flood storage. These functions help support neighboring aquatic and terrestrial ecosystems, serve to maintain surface water quality, and help to protect nearby development from flood damage.

Man-made wetlands have become a common component of the American landscape in recent years. This type of development has been primarily a result of conditions imposed on applicants for federal (mostly the U.S. Army Corps of Engineers Sections 404 and 9 permits) as well as various state permits and authorizations to develop in wetlands.

Wetlands commonly have been credited with performing a number of natural functions, most of which have direct value to society (*1*). When wetlands are filled and built on, such functions as wildlife habitat, flood control, and water purification are permanently diminished or even entirely lost, and resource or permitting agencies are increasingly demanding the creation of wetlands to compensate for these lost functions.

Much has been written, however, concerning several unsuccessful attempts to create functional wetlands. Examples range from outright failure to establish wetland vegetation (*2, 3*) to quantitative studies comparing natural and artificial wetlands for various floral, faunal, and sediment characteristics (*4*). The ultimate indicator of success is often considered to be how well the created wetland replicates the one destroyed, that is, to what extent the original wetland functions and values are replaced (*5*).

The New Jersey Department of Transportation (NJDOT) is becoming increasingly involved in wetland creation to help mitigate the impact to wetlands after the development of various roadway construction projects. In 1986, the NJDOT completed construction of a new, high-level bridge to replace an existing, deteriorated structure carrying U.S. Route 130 over the Rancocas Creek in Burlington County, New Jersey. Construction of the new bridge, near the confluence of the Rancocas with the Delaware River, required the filling of 2.3 acres of freshwater tidal wetland dominated by *Zizania aquatica* (wild rice), *Sagittaria latifolia* (arrowhead), *Polygonum* spp. (smartweeds), and *Peltandra virginica* (arrow arum) (Figure 1). Permits were issued for the construction by the U.S. Army Corps of Engineers and the New Jersey Department of Environmental Protection. As a condition of these permits, the agencies required that a total of 4.45 acres of freshwater tidal wetlands be created in the project area as mitigation for the loss of existing wetland values. The wetlands were constructed at two sites: Site 3 in 1984 (1.35 acres) and Site 1 in 1986 (3.1 acres). Existing substrate at both sites was sand, which was graded down to provide for inundation during high tide of between 1.0 and 2.2 ft of water. Both creation sites are inundated by high tide twice daily and drain completely at low tide. (The central portion of Site 1 is slightly higher in elevation to facilitate drainage into a peripheral tidal ditch, thus avoiding ponding at low tide.) The sites were planted with three perennial wetland species: *Peltandra virginica*, *Sagittaria latifolia*, and *Pontederia cordata* (pickerelweed).

Both sites have exhibited a successful establishment of vegetation, and all permit conditions are considered completely satisfied. But additional questions can be asked. In what ways are these created marshes functioning as wetland systems? Are they more than merely assemblages of wetland flora, spacially and hydrologically isolated, as some past attempts have been described?

MATERIALS AND METHODS

In an attempt to determine what wetland functions can be confidently attributed to a created wetland (specifically Site 1), NJDOT ecologists performed the following studies during the summers of 1986 through 1988.

Vegetation Survey

A total of 27 one-square-meter sample quadrats were located at random on the marsh in September 1986 and again in 1987. The number of individuals of each plant species was recorded at each quadrat, along with the percent areal cover for each species.

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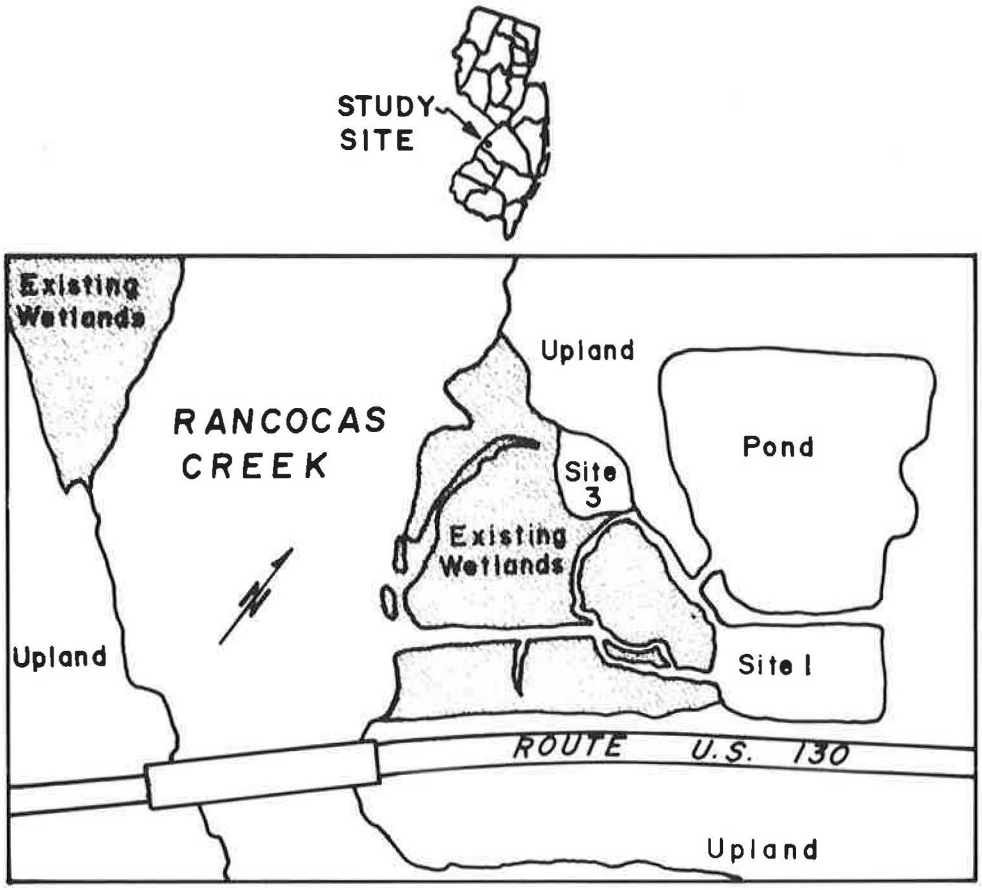

FIGURE 1 Study area showing the two created marsh sites (Sites 1 and 3).

Fish and Wildlife

Benthic macroinvertebrates were qualitatively sampled in September 1987. Portions of the peripheral tidal ditch and the marsh surface were closely observed, and individuals of all invertebrate species noticed were hand captured and immediately preserved in a 10 percent formalin solution and taken back to the laboratory for identification. In August 1988, benthic macroinvertebrates were again sampled at three tidal ditch and two marsh sites. Three samples were taken at each site by using a standard lightweight Ekman dredge and preserved in a 10 percent formalin solution. All samples were washed through a No. 30 U.S. standard sieve in the laboratory, and individual specimens were isolated and identified from the residue.

Fish were also sampled in September 1987 with a handheld seine net. Fish were netted along random sections of the tidal ditch surrounding the marsh at low tide. Representatives of all fish species collected were immediately preserved in a 10 percent formalin solution and taken back to the laboratory for identification.

All bird species observed during field visits for sampling of vegetation, sediment, or any other reason throughout the study period were recorded. Some periods of observation occurred from an adjacent upland, before entering the marsh, to minimize disturbance.

Observations of mammals and signs of their presence were also recorded during all field visits.

Sediment Depth

The depth of sediment deposited over the original sand substrate of the created marsh was measured at 21 sites in June 1988. Soil pits were dug at each sample site into the original sand layer, and a vertical surface was carefully carved out to expose the sand-sediment boundary without compaction or distortion of the layers. The boundary between original sand and sediment deposited on the marsh since its creation was easily discernible because of an abrupt change in color and texture. The depth of deposited sediment was directly measured with a plastic metric ruler.

RESULTS

Table 1 shows the dominant plant species of the created marsh in 1986 and 1987. Data have been converted to frequency (the number of quadrats in which the species is found, expressed as a percentage of the total number of quadrats), density (the number of individuals per square meter), and average absolute cover (the average of the areas of each quadrat covered by the species, as a percent). The table shows that unplanted, volunteer species have become well established. *Polygonum hydropiper* and *Ludwigia palustris* (water-purslane) maintained their dominance over both years. Of the planted species, only *Peltandra virginica* remains among the dominants. *Pontederia cordata* and *Sagittaria latifolia* both showed less

TABLE 1 DOMINANT PLANT SPECIES OF THE CREATED MARSH

Species[a]	Frequency (%)[b]	Density[b]	Average Cover (%)[b]
1986 (Total No. of Species, 19)			
Polygonum hydropiper	44	2.3	8
Ludwigia palustris	33	18.2	7
Peltandra virginica	44	0.9	5
Polygonum lapathifolium	19	0.6	1
Panicum sp.	30	0.4	1
1987 (Total No. of Species, 15)			
Polygonum hydropiper	100	110.4	72
Peltandra virginica	52	1.1	8
Ludwigia palustris	26	14.0	7
Polygonum arifolium	37	0.6	2
Polygonum sagittatum	15	0.8	1

[a]Species listed are those that showed an average cover ≥ 1 percent.
[b]See Results section of text for definitions of frequency, density, and average cover.

than 1 percent cover in 1986 and 1987. Late in the 1987 growing season, when the vegetation sampling was done (September), *Polygonum hydropiper* could be observed covering most of the marsh, and the density and average cover results for 1987 reflect the fact that by the end of the second growing season, there were few bare patches left on the marsh.

Macroinvertebrates found using the created marsh included the following: isopods (*Asellus* sp.), amphipods (*Gammarus fasciatus*), one species of freshwater snail (*Physa* sp.), three species of freshwater clam (*Anodonta* sp., *Sphaerium* sp., and *Pisidium* sp.), eastern crayfish (*Cambarus bartoni*), and chimney crayfish (*C. diogenes*). The snails were common on the marsh, particularly along the tidal ditch.

Several individuals of the following fish species were netted in the created marsh in September 1987: *Fundulus diaphanus* (banded killifish), *F. majalis* (striped killifish), *F. heteroclitus* (mummichog), *Ictalurus nebulosus* (brown bullhead), and *Lepomis macrochirus* (bluegill sunfish). Although these fish were netted from the peripheral tidal ditch built around the marsh, large schools of such fish have been observed on the marsh at intertidal periods or in marsh depressions during low tide.

Birds and mammals (or their signs) observed on the created marsh and its borders are the following:

Birds:	
Great blue heron	(*Ardea herodias*)
Snowy egret	(*Egretta thula*)
Canada goose	(*Branta canadensis*)
Mallard	(*Anas platyrhynchos*)
Killdeer	(*Charadrius vociferus*)
Mourning dove	(*Zenaida macroura*)
American goldfinch	(*Carduelis tristis*)
Song sparrow	(*Melospiza melodia*)
Eastern kingbird	(*Tyrannus tyrannus*)
Common grackle	(*Quiscalus quiscula*)
American robin	(*Turdus migratorius*)
Red-winged blackbird	(*Agelaius phoeniceus*)
Mammals:	
Muskrat	(*Ondatra zibethica*)
Raccoon	(*Procyon lotor*)
Red fox	(*Vulpes fulva*)
Groundhog	(*Marmota monax*)

Killdeer are commonly seen foraging on the marsh at low tide in early and midsummer when bare patches of mud remain. Canada geese are the most commonly seen waterfowl on the marsh, and adults and goslings regularly feed on the marsh at low tide. Muskrat and raccoon tracks are often seen in the marsh sediment, particularly along the ditch surrounding the marsh. Groundhogs burrow into areas of the berm and upland surrounding the marsh and are able to come onto the marsh at low tide.

The entire created marsh is covered by a layer of silty, very dark gray sediment that has been deposited since it was opened to tidal inundation in the spring of 1986. Figure 2 shows the depth of sediment at 21 sample sites on the created marsh. Although the results exhibit some variability (the range is 0.6 to 16.0 cm), two general trends in deposition of sediment can be seen. One is that deposition appears to be greater near the peripheral tidal ditch than in the interior of the marsh, which is a phenomenon supported by previous studies. Freshwater and saline tidal wetlands commonly exhibit slightly elevated levees along creek margins, where a large portion of sediment carried over the marsh by overflowing tides is deposited (*6,7*). The second trend that is visible in Figure 2 and readily evident from a visit to the marsh is that the southern portion (approximately one-third) of the marsh is covered by a deeper sediment layer. Walking in this area can be difficult at low tide as heavy, wet sediment clings to one's boots. This locally high deposition rate is presumably due to specific hydrologic conditions associated with the southern portion of the marsh.

DISCUSSION OF RESULTS

The Rancocas Creek created marsh possesses a developing ecosystem structure and provides several important wetland functions. The following discussion primarily highlights those functions indicated by the results of the study.

Productivity, Food Chain Support, and Fish and Wildlife Habitat

Simpson et al. (*8*) report that peak above-ground standing crop values for freshwater tidal wetlands have a range of 566–

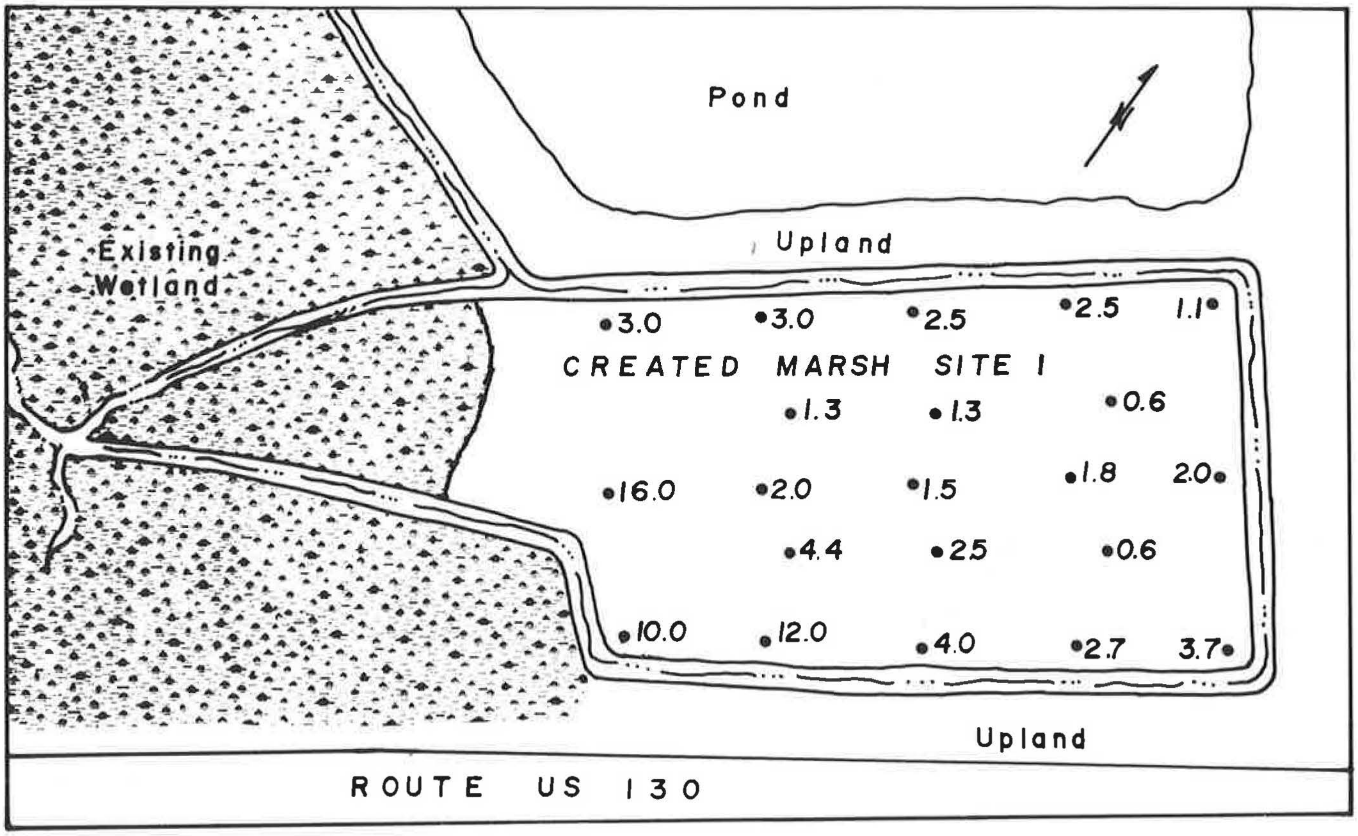

FIGURE 2 Created marsh Site 1 showing 21 sediment-depth sample locations. Values represent depth of sediment in centimeters.

2,312 g/m². Compared with other wetland or terrestrial ecosystems, freshwater tidal wetlands can be highly productive.

The created marsh Site 1 is obviously exhibiting primary productivity during the growing season. By September 1987, emergent annual and perennial plant species provided good cover throughout the marsh, as confirmed by the data from Table 1. Although accurately quantifying primary productivity in freshwater tidal wetlands can be difficult for several reasons (*9*), there are some productivity studies in the literature to which comparisons can be made. Odum et al. (*9*) summarized the results of several primary productivity studies for freshwater tidal wetlands in the mid-Atlantic region. The authors grouped the results for various vegetation types, or communities, stating that "density of vegetation and species composition . . . greatly influence production estimates" (*9*, p. 41). The two vegetation types discussed that most closely relate to the vegetation of created marsh Site 1 were arrow arum-pickerelweed and smartweed-rice cutgrass. The average above-ground peak standing crop for an arrow arum-pickerelweed marsh according to Odum et al. is relatively low (671 g/m²), whereas the smartweed-rice cutgrass peak standing crop value (1,207 g/m²) is among the moderate to higher averages reported for freshwater tidal marsh plant communities. Given the high frequency, density, and cover values for 1987 shown in Table 1 (particularly for the smartweed *Polygonum hydropiper*), it can be assumed that the created marsh productivity is similar to that given for the smartweed-rice cutgrass community. The Rancocas Creek-created marsh productivity would certainly be higher than a typical marsh entirely dominated by *Peltandra virginica* (arrow arum), whose leaves are composed primarily of water and aerenchymatous tissue (*9*), providing less dry weight biomass for a given degree of cover than species with more structural tissue (*8*). Doumlele (*10*) gave above-ground biomass and cover values for dominant species in a *Peltandra virginica* freshwater tidal marsh in Virginia for 5 months of the growing season. Annual production for the wetland was 775.74 g/m², with *Peltandra virginica* accounting for 423.4 g of that while exhibiting 38.7 percent cover. For all other species reported there was a combined cover of 16.9 percent. The average cover for *Polygonum hydropiper* alone in the Rancocas Creek created marsh for 1987 was 72 percent, which when compared to the Doumlele data also indicates a relatively high productivity. So, although a single, quantitative estimate of productivity for the Rancocas Creek created marsh cannot be given, it can be concluded that after only two growing seasons, the marsh's productivity is well within the expected range for natural marshes along the mid-Atlantic coast.

Freshwater tidal wetlands support mostly detritus-based food chains (*8*), and the Rancocas Creek created marsh is an example of this. As the end of the growing season approaches, the created marsh shows a high standing crop, as evidenced by the data in Table 1, but by midwinter the marsh is essentially a mud flat at low tide, stripped of all macrophytic vegetation. The daily tidal action of the created marsh flushes much of the dead plant material quickly out of the marsh, where it becomes available to support the aquatic food chains of the Rancocas Creek and Delaware River. Plant detritus that remains on the surface of the marsh and creek beds is consumed by benthic invertebrates, such as isopods, amphipods, insect larvae and snails, which in turn become food for various fish, birds, and mammals. Some direct grazing of vegetation does occur on the created marsh, however. *Polygonum* sp. seeds, considered important food for waterfowl and some songbirds (*11*), are plentiful on the marsh surface or floating at high tide in late summer. Muskrat are known to feed extensively on above- and below-ground parts of many plant species, including *Peltandra virginica* (*9*), and muskrat activity is evident in the created marsh. Canada geese are often seen on the created marsh feeding off the marsh surface at low tide, and the tidal ditch surrounding the entire marsh provides open water for ducks and wading birds to feed from even at low tide.

The fish species netted along the Rancocas Creek created marsh are all among the most common found in mid-Atlantic freshwater tidal marshes (*9*). The two species of killifish found are eaten by numerous larger fishes and wading birds (*9*), and as such are important food web components. In a recent study of fish use in tidal freshwater marshes and streams in Virginia, mummichogs and banded killifish were two of the most common fish netted (*12*). The authors concluded that the tidal freshwater marsh studied was heavily used by juveniles and may be an important nursery area, and that "marshes located at the upper reaches of tidal creeks support greater densities of fishes than marshes farther downstream" (*12*, p. 42). The Rancocas Creek created marsh is itself in a tidal headwater location, and its position in a well-developed creek system (Figure 1) coupled with its own peripheral ditch (Figure 2) probably serve to make it more productive for fish than a fringe marsh along a river (*12*).

Sediment Trapping and Nutrient Cycling

Accretion of clays and silts generally occur in freshwater tidal marshes (*9*). Accretion rates of mid-Atlantic freshwater tidal marshes are not well documented in the literature, where more attention has been focused on salt marshes. Hatton et al. (*13*) reported sediment accretion rates in a freshwater tidal marsh in Louisiana of 10.6 mm/year at a levee site and 6.5 mm/year in the backmarsh. Orson (unpublished presentation to New Jersey Academy of Science, Annual Meeting, 1988) reported an annual accretion rate for recent years of 1.2 cm/year in a freshwater tidal marsh along the Delaware River in New Jersey. Unpublished data from the natural Rancocas Creek freshwater tidal marsh near the U.S. Route 130 bridge (Orson, personal communication, 1988) show a similar sedimentation rate.

As reported, sediment depths at the Rancocas Creek created marsh show some variability, with a mean for all samples of 3.7 cm (coefficient of variation = 1.07). Less variability is shown by breaking up the results into two groups: levee sites along the peripheral tidal ditch (mean = 5.2 cm; coefficient of variation = 0.9) and interior sites (mean = 1.8 cm; coefficient of variation = 0.65). Regardless of the data variability, an average accretion rate of 1.2 cm/year for area marshes as reported by Orson is within the range found at the created marsh of 0.6–16.0 cm over an approximate 2-year period (0.3–8.0 cm/year).

Nutrient cycling in freshwater tidal marshes is a complex process varying seasonally (*6*). Generally, the marshes tend to import nutrients associated with plant uptake during the spring and summer. Nutrient export occurs during the fall as detritus washes off the marsh. In this manner, freshwater tidal marshes act primarily as nutrient transformers (*9*). Based on the plant productivity of the Rancocas Creek created marsh, and the detrital export washing into the Rancocas Creek at the end of the growing season, it is acting to transform nutrients from inorganic, oxidized forms to reduced compounds, usable by consumers. A significant degree of net nutrient retention may also be occurring in the created marsh, as nutrient-laden sediments are accreting on the surface as reported.

Flood Storage

The Rancocas Creek created marsh is within the 100-year floodplain of Rancocas Creek, according to the National Flood Insurance Program, Flood Insurance Rate Maps. The upland berm surrounding the marsh is at least 4 ft higher than the elevation of an average high tide on the marsh, providing additional storage for storm tides within the marsh. Flood storage is valuable in the project area, where development has encroached on several areas of the Delaware River floodplain.

In conclusion, the Rancocas Creek created marsh is a young but functioning wetland, with a developing ecosystem structure. Important environmental functions provided by the marsh include primary productivity and food chain support, fish and wildlife habitat, sediment trapping, nutrient transformation (and perhaps retention), and flood storage. These functions help support neighboring aquatic and terrestrial systems, since the created marsh is neither hydrologically nor biologically isolated. Those functions that serve to improve surface water quality, such as sediment trapping and nutrient retention, have great social importance in the area, since municipal water supply intakes (most notably the city of Philadelphia's) occur downstream.

ACKNOWLEDGMENT

The author wishes to express his thanks to his co-workers for their indispensable help in data collection, as well as to his wife, Rocie, for her continuous encouragement and advice.

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Publication of this paper sponsored by Committee on Landscape and Environmental Design.