1991

Nutrient Standing Stocks and Partitioning in a Forested Coastal Plain Watershed: Groundwater, Stream and Marsh Creek

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Recommended Citation

Hartenstine, Sandra A., "Nutrient Standing Stocks and Partitioning in a Forested Coastal Plain Watershed: Groundwater, Stream and Marsh Creek" (1991). *Dissertations, Theses, and Masters Projects.* Paper 1539617639.
https://dx.doi.org/doi:10.25773/v5-fb1h-h702

NUTRIENT STANDING STOCKS AND PARTITIONING IN A FORESTED COASTAL PLAIN WATERSHED: GROUNDWATER, STREAM AND MARSH CREEK

A Thesis

Presented to

The Faculty of the School of Marine Science

The College of William and Mary in Virginia

In Partial Fulfillment

Of the Requirements for the Degree of

Master of Arts

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by

Sandra A. Hartenstine

1991

APPROVAL SHEET

This thesis is submitted in partial fulfillment of
the requirements for the degree of

Master of Arts

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DEDICATION

This thesis is dedicated to Richard Scott Williams
for his patience and sacrifices.

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ACKNOWLEDGEMENTS

Sincere thanks go out to a number of people who made this study possible: Dick Wetzel, for his careful review, patience, and guidance; Scott Williams, Matt Breaks, and Joan Campbell for their field assistance; Stephanie Turner, for her help with site selection and equipment placement; Gary Anderson, Jerre Johnson, and Willy Reay for all of their help; and Betty Berry, for her patience in the laboratory. I am grateful to Carl Hershner, Woody Hobbs and Bruce Neilson for their careful review of this work. I would also like to thank my sister and my parents for their understanding and express a special thank you to Carroll Curtis for her guidance, support, and friendship.

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ABSTRACT

This study investigated the nutrient standing stocks in a small, pristine, bottomland hardwood swamp and partitioned the nutrient sources and sinks at the marsh/upland interface. Nutrient concentrations of water samples collected during two hydroperiods in 1990 in the Taskinas Creek watershed of the York River Estuary, Virginia, showed the importance of groundwater as a potential source of nutrients to the system, particularly during the spring hydroperiod. Observed orthophosphate concentrations were high during both hydroperiods at all sampling stations. Groundwater concentrations ranged from 1.37 to 6.78 ug-at/L during the spring hydroperiod and from 1.44 to 12.52 ug-at/L during the summer hydroperiod. Nitrate+nitrite concentrations were greatest in Taskinas Creek during the spring hydroperiod ranging from 0.87 to 14.90 ug-at/L. During the summer hydroperiod, the stream exhibited the greatest concentrations of nitrate+nitrite ranging from 1.50 to 2.56 ug-at/L. Ammonium concentrations generally were highest in the groundwater during the spring ranging from 0.41 to 4.56 ug-at/L while the highest summer ammonium concentrations fluctuated between the groundwater and stream sampling stations. Groundwater ammonium concentrations ranged from 1.37 to 6.57 ug-at/L and the stream station ranged from 2.22 to 3.50 ug-at/L during the summer hydroperiod. The Taskinas Creek sampling station showed great variation in nutrient concentrations, presumably due to York River influence. The results indicate that during the spring groundwater acts as an ammonium source for the stream. The results indicate that spring groundwater also may be an important source of nitrate+ nitrite, while groundwater may serve as a source for orthophosphate in the system in both hydroperiods.

NUTRIENT STANDING STOCKS AND PARTITIONING IN A FORESTED COASTAL PLAIN WATERSHED: GROUNDWATER, STREAM, AND MARSH CREEK

INTRODUCTION

Bottomland hardwood forest ecosystems include extensive palustrine forested wetlands in the southeastern United States. These areas are characteristically found on river floodplains and streambanks with soils that are saturated periodically by surface or groundwater during the growing season. Frequently they are narrow, being located along rivers and streams. The vegetation associated with these regions contains a diversity of trees adapted to a wide range of environmental conditions, woody species in the understory, and marsh species on the floodplain. These ecosystems possess large transition zones where aquatic and terrestrial ecosystems interface, providing important exchange sites for material and energy in the landscape (Brinson et al. 1981). Bottomland hardwood wetlands are of particular interest due to their rapid conversion to agriculture or development. More than 70% of the riparian ecosystems have been altered. Natural riparian communities now make up less than 2% of the land area in the United States (Brinson et al. 1981). It is estimated by the United States Fish and Wildlife Service (Wilen and Frayer 1990) that during the 1950's riparian ecosystems made up approximately 6% of the land area of the United States and that palustrine vegetated wetlands have decreased from 40 million hectares in the 1950's to 36 million hectares in the 1970's with an average annual loss of 216,000 hectares. Palustrine forested-wetland (swamps) losses accounted for 122,000 hectares (net average annual loss), while palustrine emergent-wetland (inland marshes and wet meadows) losses accounted for a net average annual loss of 95,000 hectares a year (Wilen and Frayer 1990).

Due to their location along streams and rivers, the seasonal cycle in the bottomland hardwood system tends to be defined more by precipitation and flooding than temperature (Gosselink and Lee 1989). Rising waters in the late winter and spring typically flood the forest floor and determine, to a great degree, the flora and fauna which inhabit the floodplain. Diversity and productivity are high in the bottomland hardwood wetland system due to the presence of marsh species and hardwood trees which flower and/or produce fruit for a large portion of the year. During the summer the floodplain buffers the adjacent stream from the uplands. Species composition and density all play an important role in productivity and nutrient cycling in these environments. General aspects of nutrient cycling in these systems has been described by Brinson et al. (1981), revealing a complex series of interactions among the soils, vegetative cover, hydrology, and organisms. Flooding also plays a key role in the nutrient cycles of these wetlands.

Groundwater discharge to estuarine waters has been recognized as a potential nutrient source (Valiela et al. 1978; Valiela et al. 1990; Capone and Slater 1990) and has recently attracted much scientific attention. Field measurements have shown the importance of shallow, subsurface flow on nutrient budgets of the estuary. In cases where the soils are coarse and unconsolidated, groundwater may be the major source of nutrients. In the last ten years the transport of nutrients into coastal waters by groundwater has been shown to be more significant than previously realized (Capone and Bautista 1985; Giblin and Gaines 1990). Valiela and colleagues (1990) determined that the importance of groundwater was not so much due to the magnitude of flow rates, but due to the high nutrient concentrations in groundwater compared to those in receiving seawater. Evidence also suggests nutrient content of groundwater may be up to five orders of magnitude higher than the nutrient content of receiving seawater (Valiela et al. 1978; D'Elia et al. 1981).

The objective of this study was to investigate the standing stocks of nutrients and partition nutrients at the marsh/upland interface of a small, unimpacted bottomland hardwood forest during two hydroperiods. One hydroperiod was characterized by high precipitation and runoff, the other by low precipitation and runoff. The study focused on the nutrient concentrations of groundwater and stream water in the Taskinas Creek watershed of the York River Estuary, Virginia (Figure 1). The data also serve to establish baseline water quality conditions in the region.

LITERATURE REVIEW

Bottomland hardwood forests were classified according to flooding conditions and divided into zones by the Society of American Foresters at a workshop held at Lake Lanier, Georgia in 1980. The zones range from intermittently exposed (Zone II) to intermittently flooded (Zone VI). Zone VI ecosystems usually are not considered wetlands but a transition zone to the uplands (Mitsch and Gosselink 1986). The riparian wetlands generally have ample nutrients whose availability is modified by flooding conditions. Flooding creates a reduced oxidation state in the soils and often is accompanied by a shift of pH and mobilization of phosphorus, nitrogen, copper, and other soil nutrients and minerals. Regions of oxic and anoxic conditions also may develop during flooding and denitrification may become more prevalent. These alternating conditions also slow down decomposition. The wetting and drying of the soils is important in releasing nutrients from leaf litter. The major limiting factor in these ecosystems may be the physical stress of inadequate oxygen to the root systems during flooding rather than inadequate supply of a specific nutrient or mineral (Wharton et al. 1982).

The overall function of these ecosystems is poorly understood. It is recognized that productivity in these wetlands is greater than in the adjacent uplands and that these systems are subjected to large fluxes of energy and nutrients, usually on a seasonal basis (Brinson et al. 1981; Mitsch and Gosselink 1986). Bottomland hardwood ecosystems have been observed to act as a nutrient sink for upland runoff and an important component in the nutrient cycle of the entire watershed (Brinson et al. 1981). These systems collect and effectively filter nutrients that enter through runoff and groundwater. Peterjohn and Correll (1984) estimated that a 50 meter wide riparian forest in a small agricultural watershed in the Rhode River drainage basin in Maryland retained 89 percent of the nitrogen inputs and 80 percent of the phosphorus inputs. They concluded that an insufficient number of studies have been conducted to assess how common these observed effects were.

Brinson et al. (1981) described the nitrogen cycle in a bottomland hardwood stream-floodplain complex. They noted that winter flooding contributed dissolved and particulate nitrogen to the system, which was not taken up by the dormant canopy trees, but which was taken up by filamentous algae on the forest floor and immobilized by detritivores. In the spring the algae were shaded by the developing canopy and released nitrogen. As vegetation continued to grow, nitrogen uptake increased. Lowering water levels exposed the soil's surface and ammonification and nitrification increased, making nitrogen more available for plant uptake. Nitrification produces nitrates which are lost through denitrification caused by the subsequent flooding and anaerobic conditions.

Nutrient mass balances for parts of the Rhode River estuary of the Chesapeake Bay in Maryland were determined for a 13-month period (Correll 1981). The intertidal zone of this study was an estuarine-headwaters habitat and received large volumes of land drainage in addition to having tidal exchanges with the estuary. Land runoff was shown to have an important effect on the mass balance of the ecosystem, with its large amounts of nutrients and flushing effect on buffer zone waters. The importance of precipitation and both surface and groundwater inputs was stressed.

Groundwater has been determined to be a major source of nutrients in many coastal environments (Correll 1981, Giblin and Gaines 1990, and Harvey and Odum 1990). Harvey and Odum (1990) studied the influence of tidal marshes on the groundwater discharge in two estuaries of the Chesapeake Bay in Virginia. Transects using piezometers and pore water samplers were arranged from the base of the hillslope across the marsh perpendicular to the marsh-hillslope interface. Maximum groundwater discharge occurred close to the base of hillslopes and declined with distance away from the slope. This is supported by other field observations (Capone and Bautista 1985; Valiela et al. 1980). Harvey and Odum (1990) determined that upland elevation, slope and soil type were the controlling factors in discharge rates of groundwater. The results of their study showed that hydraulic head was greater in the underlying aquifer and upward hydraulic gradient beneath the marsh was evidence that groundwater is being discharged into the marsh from the soil below. Harvey and Odum's (1990) results also indicated that where clay or organic muds were present, groundwater discharge was small and areas with thin clay or organic layers permitted groundwater discharge up to two orders of magnitude higher. The study concluded that groundwater discharged from the upland aquifer was retained longer and became more thoroughly mixed with the pore and surface water in tidal marsh soils. The longer soil contact time was thought to be important in nutrient immobilization and in modulating biogeochemical reactions. The study pointed out that very shallow groundwater flow from near the surface, hillslope soils may be an important transport pathway.

The importance of nitrogen inputs from groundwater and runoff were evaluated by Giblin and Gaines (1990) in their study focusing on a small cove on Cape Cod, Massachussetts. The dominant form of inorganic nitrogen in the groundwater samples, wells, seeps, and springs around the cove was nitrate, which appeared to be largely derived from septic systems. Patterns of nitrate and salinity in pore waters indicated a high groundwater flow in sandy areas and very low or no groundwater flow in the muddier areas. It was concluded that nitrogen loading, when adjusted for the volume of the ecosystem, from groundwater and runoff were similar in magnitude to river dominated estuaries in urbanized areas of the United States.

Another study in the Rhode River estuary in Maryland investigated precipitation and land runoff as sources of nitrogen to the estuary (Correll and Ford 1982). The importance of estuarine nitrogen loading due to precipitation was assessed by studying the temporal pattern of nitrate and ammonium concentrations in the estuary. It was determined that nitrate and ammonia loading via precipitation was most important in the summer and fall relative to surface water concentrations. The relative importance of precipitation as a source of estuarine nitrogen was observed to be greatest in warm weather when land runoff was low and its associated nitrate concentration was also low. The results showed that nitrate in bulk precipitation at Rhode River was present at essentially double the concentration of ammonium, and has been increasing steadily for seven years.

Harvey and Odum (1990) noted that there is a renewed attention to the interconnectedness between upland aquifers and fringing tidal marshes, and the role of marshes in modifying subsurface fluxes between the upland and the estuary. The present study was an attempt to begin to understand the standing stocks and sources of nutrients in a natural, iunimpacted tidal marsh-upland hardwood system of the York River estuary.

METHODS

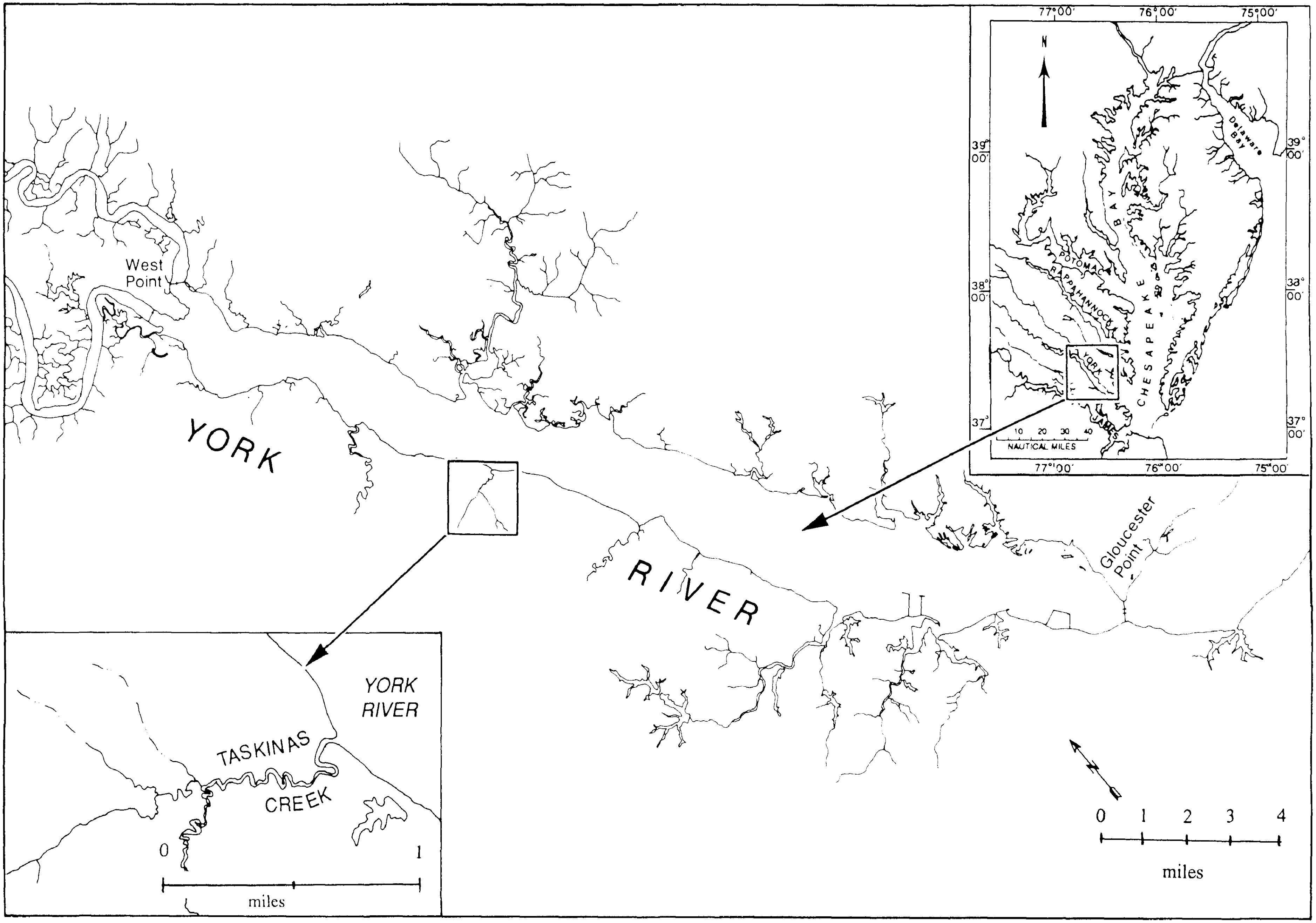
Study Site

The Taskinas Creek watershed is located on the western shore of the York River Estuary in James City County, Virginia (Figure 1). Most of the watershed is located within the boundaries of York River State Park and the proposed Taskinas Creek National Estuarine Research Reserve. Taskinas Creek is a pristine, tidal creek with several feeder streams which drain oak-hickory forests and ravines, maple-oak-ash swamps, and freshwater marshes. The lower sections of the creek are dominated by brackish water marshes. Bottomland hardwood forests fringe feeder streams at the base of the hillslopes throughout the watershed. One of the feeder streams is the focus of this study.

Upland forests cover the ridges and ravine slopes throughout this area of the watershed. The area is rugged and slopes range from 6 to 50 percent. The vegetative cover plays an important role in soil stabilization and erosion protection. The ravine slopes are dominated by chestnut oak (*Quercus prinus*), northern red oak (*Quercus rubra*), tulip poplar (*Liriodendron tulipifera*), American beech (*Fagus grandifolia*), American holly (*Ilex opaca*), and mountain laurel (*Kalmia latifolia*). The same species, as well as sycamore

Figure 1

Location of the Taskinas Creek watershed in the York River Estuary, Virginia


77°00′
76°00′
75°00′
N
39° 00′
38° 00′
37°
10 20 30 40
NAUTICAL MILES
BAY
POTOMAC
RAPPAHANNOCK
YORK
JAMES
CHESAPEAKE
Delaware Bay
West Point
YORK
RIVER
Gloucester Point
N
0 1 2 3 4
miles
YORK RIVER
TASKINAS
CREEK
0
1
miles

(*Platanus occidentalis*), Virginia pine (*Pinus virginiana*), loblolly pine (*Pinus taeda*), red maple (*Acer rubrum*), white oak (*Quercus alba*), southern red oak (*Quercus falcata*), and sassafrass (*Sassafrass albidum*) are found on the ridges.

The floodplain is vegetated with freshwater marsh species such as rice cutgrass (*Leersia oryzoides*), lizard's tail (*Saururus cernuus*), and wild anise (*Osmorhiza longistylis*). The observation of wild anise is a county record, as this species has not been documented in the county before (Perry, personal communication). The wood fern (*Dryopteris* spp.) grows on the base of the upland slope.

Berquist (1990) preliminarily mapped the geology of the area. The units exposed at the surface in the study area are the Pliocene-age Bacons Castle Formation, which is located on the ridge tops, the Pliocene-age Yorktown Formation, at the top of the ravines; and the Miocene-age Eastover Formation, found in the ravine bottoms along with marsh or swamp units.

The soils as defined by the United States Department of Agriculture, Soil Conservation Service in the Soil Survey of James City County (1980) are a complex arrangement of Emporia soils composed of fine sandy loams with a firm sandy clay substratum. This soil commonly lies over layers of fossil shells and is found on side slopes along rivers, creeks, and drainageways. The water table frequently is near the surface in perched water tables, and the region is considered to be highly erodable, especially if soil cover is removed.

The Taskinas Creek watershed in York River State Park is undeveloped, but the surrounding region is of mixed, low-density residential and agriculture, forestry, and rural residential zoning areas as identified by the James City County Comprehensive Plan. The study site is located in an area of the park where public access is discouraged and subject only to natural processes.

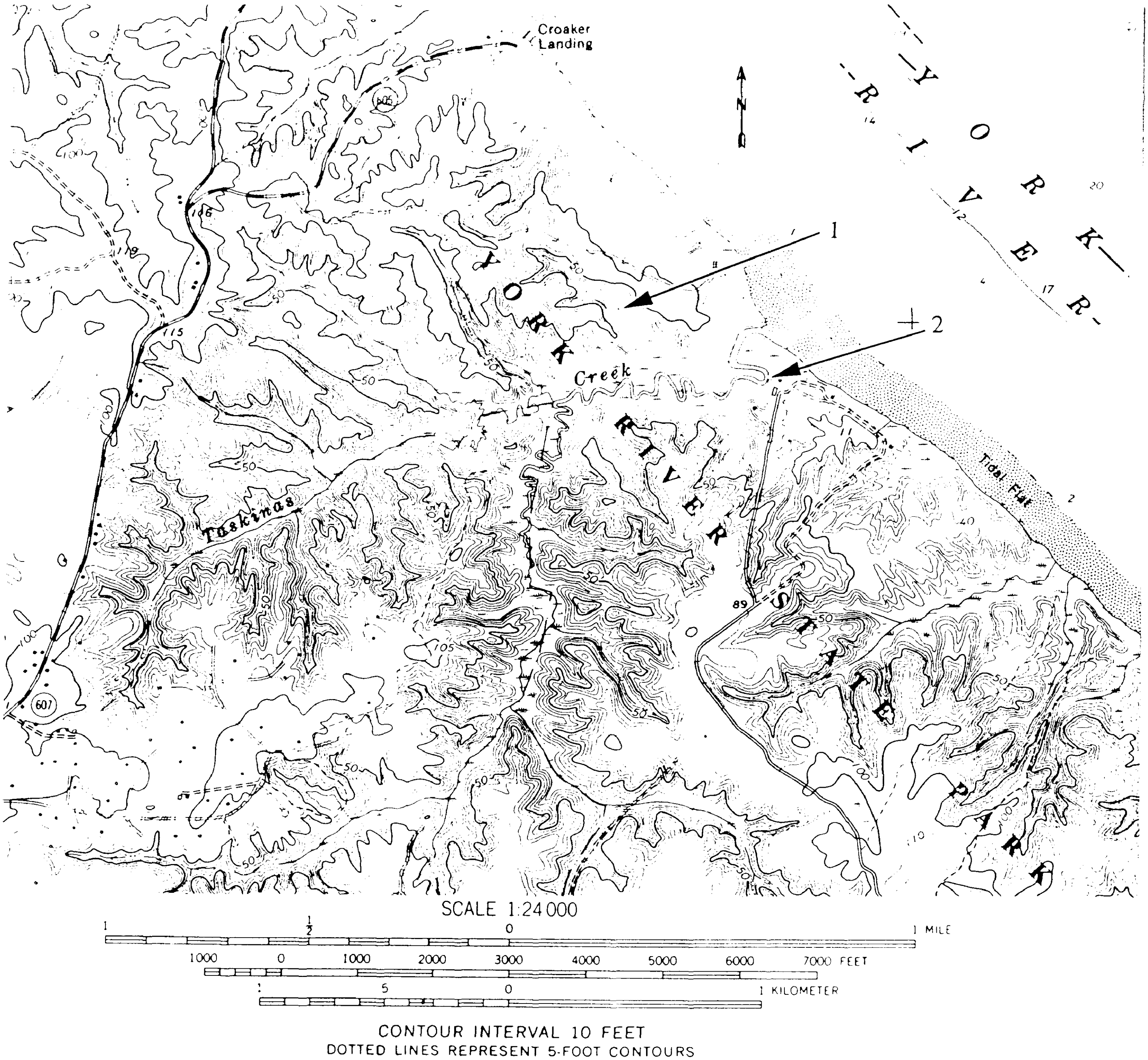
The study site is located in the humid subtropical marine climatic region and has no well defined dry season although periods of minimum rainfall generally occur in the mid and late summer. The warmest air temperatures occur in July and August and the temperature record for 1970-1981 reveals that water temperature follows air temperature with maximum temperature reaching approximately 26 degrees C in August (Brooks 1983). Mean annual precipitation for the region is 116 cm, calculated from a thirty-year record (National Climatic Data Center, 1989). Rainfall varies greatly from year to year.

Sampling Methodology

Sampling stations were established on a small, pristine headwater stream in the Taskinas Creek watershed and downstream on the tidal reaches of Taskinas Creek itself (Figure 2). The station on the feeder stream consisted of a water sample collection site, two groundwater wells and surface water collectors. The canoe-launching dock downstream provided a water sample collection site on Taskinas Creek. Water samples were collected during the spring

Figure 2

Location of sampling stations in the Taskinas Creek watershed,
York River Estuary, Virginia.
Source map: Gressitt 7.5 minute series quadrangle.



Sampling station 1 - groundwater and stream
Sampling station 2 - Taskinas Creek

hydroperiod, characterized by greater precipitation and runoff, and during the summer hydroperiod, typically low in precipitation and runoff.

The spring sampling schedule was determined by the occurrence of rain events. Beginning on March 26, 1990 and ending June 4, 1990 seven sets of samples were collected during or directly following rain events. Precipitation was collected for analyses on March 26, 1990 and April 2, 1990. The summer sampling schedule was determined by tide stage at the Taskinas Creek sampling site. Six sets of samples were collected weekly from July 18, 1990 through August 29, 1990 at ebbing tide.

The groundwater wells were constructed of polyvinylchloride slotted pipe (ASTM accepted), capped at both ends. Two wells (72 and 93 cm deep respectively) were placed one meter apart in hand-augered holes at the base of the hillslope. A bentonite seal was used to prevent contamination. Samples were collected with a Nalgene hand pump into dedicated Erlenmeyer flasks. Wells were purged and allowed to recharge before samples were removed. The sample location on the stream was marked by a small flag and represented an area where the water was deepest, approximately 5 cm. Bottles were submerged and filled at this location each time. Precipitation was collected in an open area across the marsh from the sample site. Samples were composites of a collector built to trap precipitation. The collector held six acid-washed Nalgene bottles covered with plastic mesh screening to keep out leaves and large debris. The precipitation collector was placed in the open area approximately 12 - 15 hours prior to sampling. Following removal of each sample, the collector was acid-washed and covered until the next rain event. Taskinas Creek was sampled by submerging a bottle from the same corner of the dock each time.

All samples were stored in ice and transported directly to the laboratory for analysis. pH was determined by the use of an Orion digital pH meter and salinity was determined by the use of a Rechert-Jung temperature compensated hand-held refractometer. Each sample was filtered through a precombusted GF-F filter with a vacuum pump, retaining 250 ml of each sample. Total suspended solids were determined by filtering a known volume of sample through a pre-weighed, combusted GF-F filter and placing it in a drying oven at 50 degrees C. After completely dry the filters were weighed again to determine total suspended solids concentration. Ammonium samples were treated in an alkaline citrate medium with sodium hypochlorite and phenol in the presence of sodium nitroprusside. The blue indophenol color formed with ammonia was measured spectrophotometrically (Parsons et al. 1984).

Nitrate was reduced to nitrite quantitatively by running the sample through a column containing cadmium filings coated with metallic copper. The nitrite produced was determined by diazotizing with sulfanilamide and coupling with N-(1-naphthyl)-ethylenediamine to form a highly colored azo dye which was measured spectrophotometrically (Parsons et al. 1984). Nitrite was allowed to react with sulfanilamide in an acid solution. The resulting compound was reacted with N-(1-naphthyl)-ethylenediamine to form an azo dye, which was read spectrophotometrically (Parsons et al. 1984). Orthophosphate was analyzed by the ascorbic acid method and read colorimetrically (APHA method 4500-PE 1989).

Statistical Methods

The data were analyzed by using a two sample t-test to test for a difference in mean concentrations. Triplicate concentration values for each sampling date were used. The comparisons were made between groundwater and stream, stream and Taskinas Creek, and groundwater and Taskinas Creek. Probabilities were analyzed with a 95% confidence interval for significance using a probability value of 0.1, and t statistics provided the direction of change. Pooled values were determined using all data of each constitutent for the particular hydroperiod.

RESULTS

Precipitation

Precipitation was greater during the spring hydroperiod varying from 0 to 3.92 cm daily, with monthly totals of 9.08 cm in March, 5.69 cm in April, and 12.21 cm in May. Summer precipitation varied from 0 to 0.95 cm daily, with monthly totals of 3.03 cm in July and 2.26 cm in August. Precipitation data are presented in Figure 3A and 3B. Precipitation was measured at the Virginia Institute of Marine Science, 38 km downstream from the Taskinas Creek watershed. Surface runoff was zero in both hydroperiods, with no runoff collected or observed. Precipitation samples were composites from a collector containing six bottles. Only twice during the spring hydroperiod was precipitation sufficient to collect an analyzable quantity. Samples were collected on March 26 and April 2, 1990.

Environmental Conditions

Environmental conditions during each sampling period are presented in Table 1. Air and stream water temperatures generally tracked each other and are typical for the region and time of year.

Figure 3

Precipitation recorded at the Virginia Institute of Marine Science.

(A: Precipitation in cm measured during the spring 1990 hydroperiod)

(B: Precipitation in cm measured during the summer 1990 hydroperiod)

Precipitation during 1990 hydroperiods

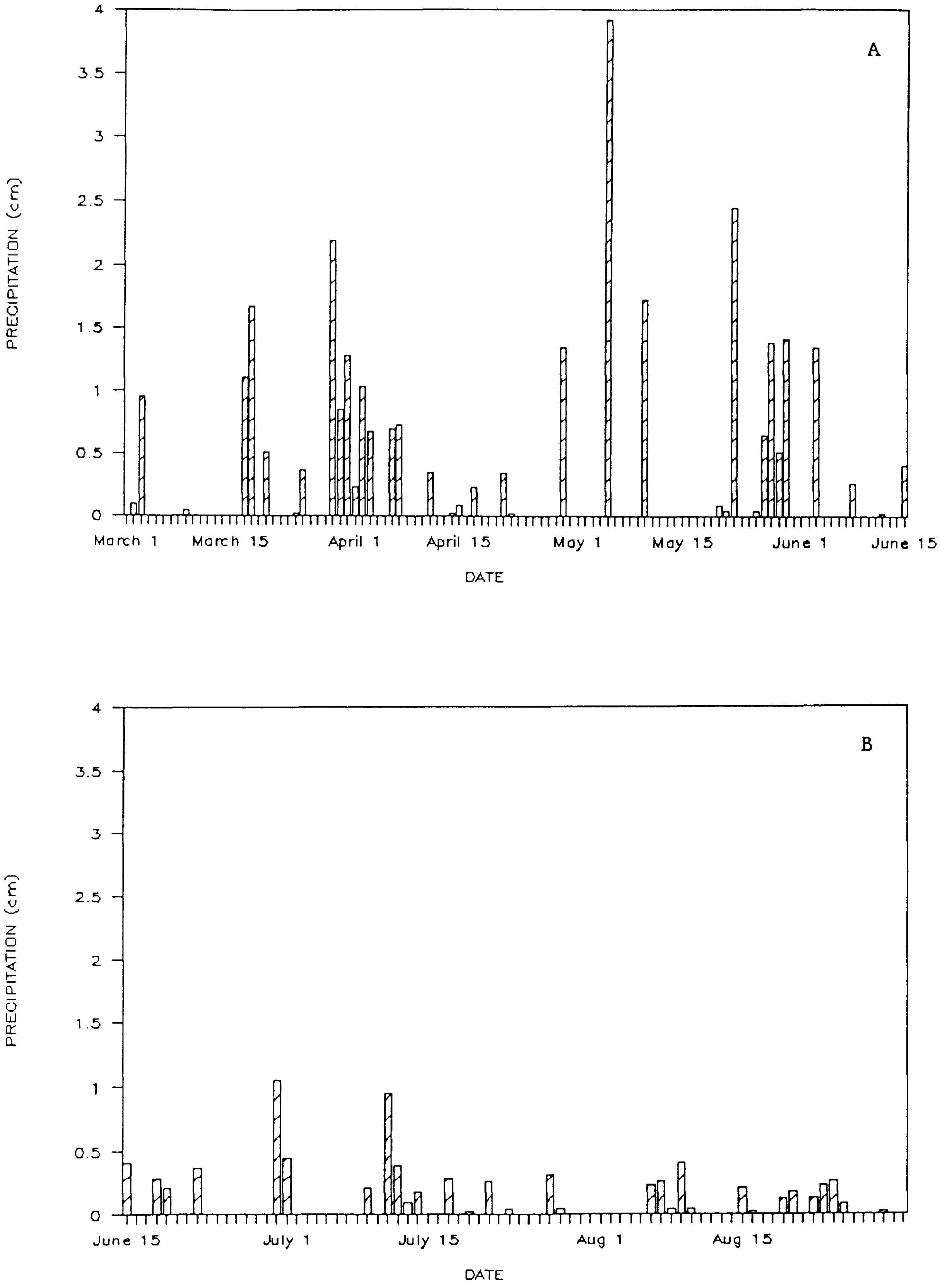


Table 1: Environmental conditions observed during the 1990 spring and summer hydroperiod sampling

Date	Time	Weather	Temperature (degrees C) Air	Temperature (degrees C) Stream	Tide stage (Taskinas Creek)
March 26	10:16 AM	Overcast, drizzle	10.3	10.9	high/ebb
April 2	10:27 AM	Overcast, drizzle	12.0	13.0	low/wk. flood
April 9	08:57 AM	Sunny, clear	10.0	11.0	low/slack
April 18	11:36 AM	Sunny, clear	20.0	14.0	low/slack
April 27	08:48 AM	Sunny, clear	22.0	17.0	low/wk. flood
May 9	10:15 AM	Sunny, clear	23.0	17.0	high/slack
June 4	09:18 AM	Pt. cloudy, humid	22.5	19.0	high/ebb
July 18	09:21 AM	Sunny, clear	23.0	21.0	high/ebb
July 25	07:45 AM	Clear, sunny	21.0	21.0	low/ebb
August 8	08:12 AM	Overcast, humid	21.0	21.0	low/ebb
August 15	08:20 AM	Pt. cloudy, hot	23.5	22.0	low/ebb
August 21	08:50 AM	Overcast, drizzle	20.0	19.5	high/wk. flood
August 29	08:25 AM	Pt. cloudy, hot	24.0	23.0	high/ebb

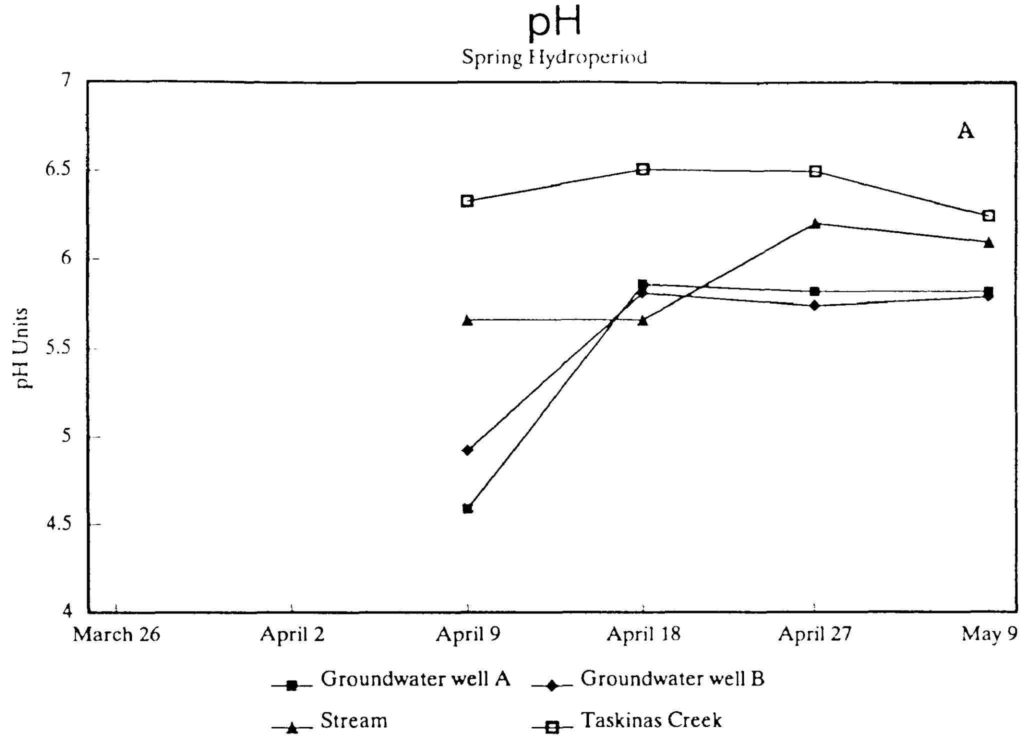
Tidal height in Taskinas Creek at the time of sample collection varied during the spring hydroperiod, but was generally ebbing during the summer hydroperiod sampling. Groundwater pH ranged from 4.59 to 5.86 during the spring hydroperiod and 5.34 to 5.97 during the summer hydroperiod. Stream pH values were higher during the summer hydroperiod, ranging from 5.97 to 6.30, while the spring pH ranged from 5.66 to 6.10. pH in Taskinas Creek was relatively constant during both hydroperiods, ranging from 6.13 to 6.86. pH data are presented graphically in Figures 4A and 4B. Salinity was measured at the stream and Taskinas Creek sampling stations. Stream salinity remained near zero parts per thousand (ppt) throughout the spring and measured 1 to 3 ppt in the summer. Salinity at the Taskinas Creek station varied due to tidal stage and ranged from 1 to 9.5 ppt in the spring hydroperiod and from 2 to 14 ppt during the summer hydroperiod. Salinity data are presented in Figures 5A and 5B. Groundwater well water levels were measured from the top of the well to the water level surface prior to sampling during each visit. Water levels in groundwater well A remained either 33.5 or 34 cm during the spring and ranged from 38 to 41 cm during the summer. Groundwater well B water levels ranged from 46 to 48 cm during the spring hydroperiod and from 53 to 55 cm during the summer hydroperiod. Due to the fact that only two replicates were collected from groundwater well B, comparisons throughout this study are based upon the information collected from groundwater well A.

Figure 4

pH observed during both 1990 hydroperiods.

(A: pH during the spring hydroperiod)

(B: pH during the summer hydroperiod)


pH
Spring Hydroperiod
A
pH Units
7
6.5
6
5.5
5
4.5
4
March 26
April 2
April 9
April 18
April 27
May 9
Groundwater well A
Groundwater well B
Stream
Taskinas Creek

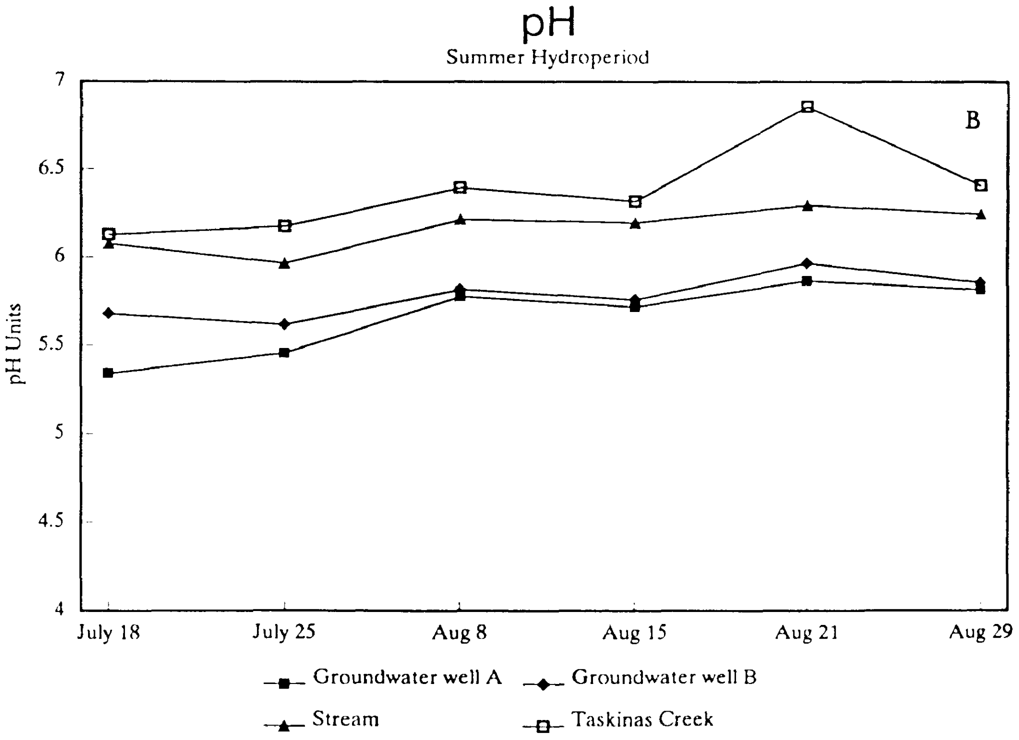
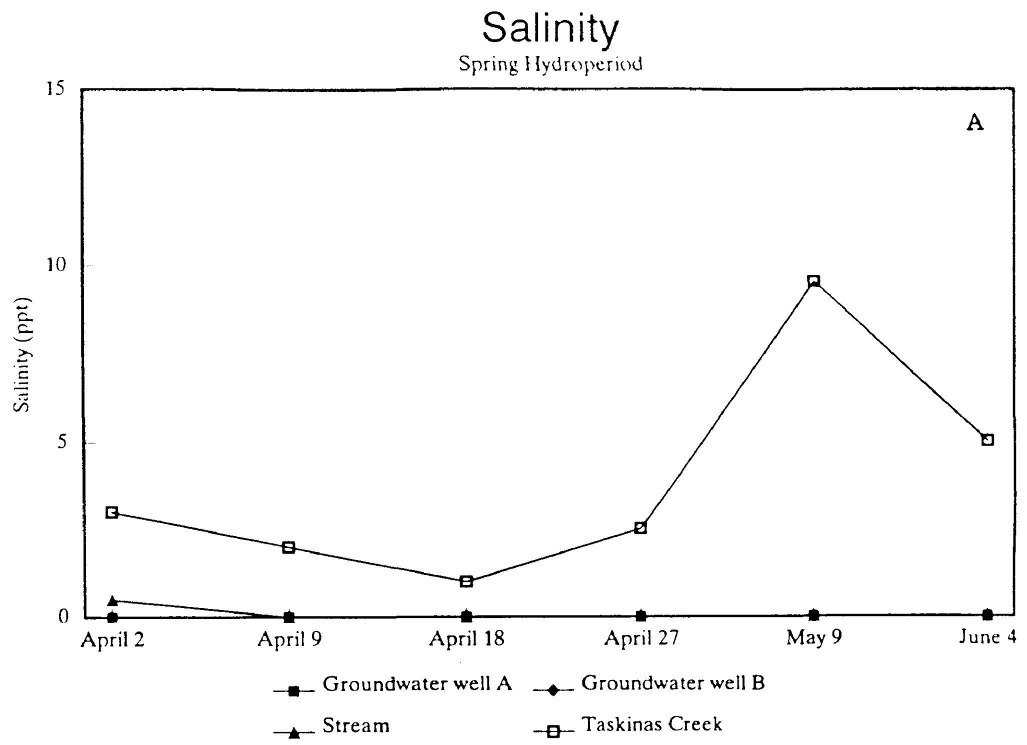

pH
Summer Hydroperiod
B
pH Units
7
6.5
6
5.5
5
4.5
4
July 18
July 25
Aug 8
Aug 15
Aug 21
Aug 29
Groundwater well A
Groundwater well B
Stream
Taskinas Creek

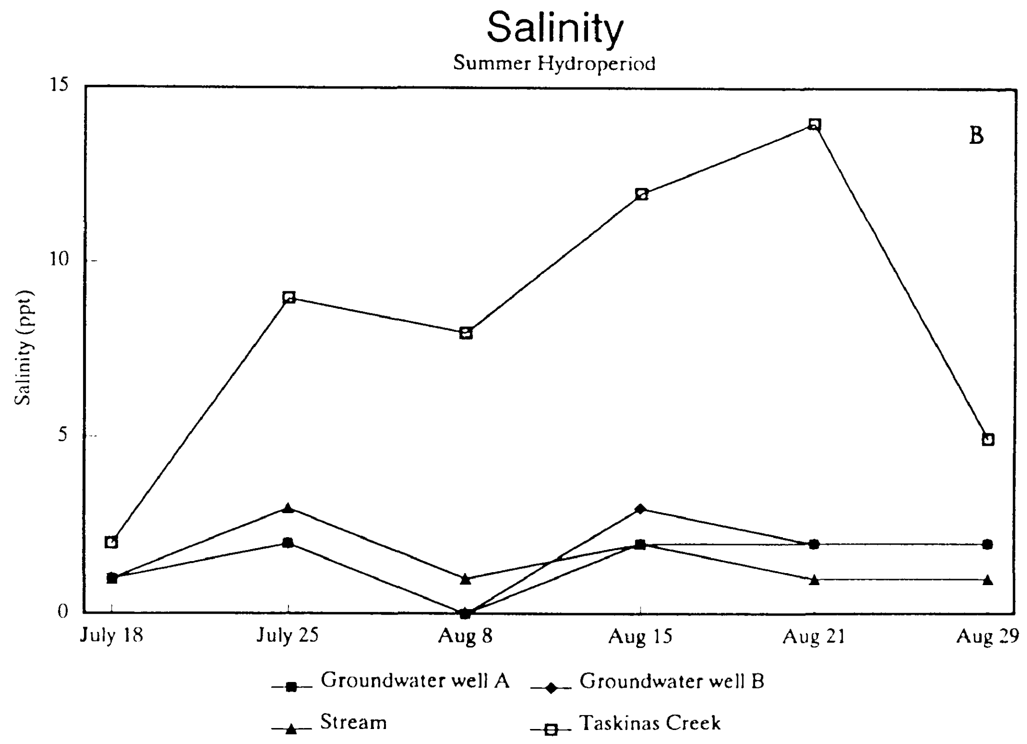
Figure 5

Salinity measurements in parts per thousand during both 1990 hydroperiods.

(A: Salinities observed during the spring hydroperiod)

(B: Salinities observed during the spring hydroperiod)


Salinity
Spring Hydroperiod
A
Salinity (ppt)
15
10
5
0
April 2
April 9
April 18
April 27
May 9
June 4
Groundwater well A
Groundwater well B
Stream
Taskinas Creek


Salinity
Summer Hydroperiod
B
Salinity (ppt)
15
10
5
0
July 18
July 25
Aug 8
Aug 15
Aug 21
Aug 29
Groundwater well A
Groundwater well B
Stream
Taskinas Creek

Nutrient Standing Stocks

Ammonium, nitrate, nitrite and orthophosphate were measured in triplicate at each of the sampling stations in this study. Raw data for this study are presented in Appendix A. All nutrient concentrations are reported in ug-at/L.

Ammonium

Ammonium concentrations for groundwater ranged from 0.41 to 4.56 ug-at/L during the spring and from 1.37 to 6.57 ug-at/L during the summer. Stream ammonium concentrations in the spring ranged from 1.05 to 4.08 ug-at/L and ranged from 2.22 to 3.50 ug-at/L during the summer. Ammonium concentrations for Taskinas Creek ranged from 0.88 to 13.88 ug-at/L in the spring, with most samples in the 2.5 to 3.9 ug-at/L range. Summer concentrations ranged from 1.63 to 6.44 ug-at/L. For the two precipitation samples ammonium concentrations were 6.92 and 6.16 ug-at/L.

Ammonium concentrations observed at the Taskinas Creek sampling station were greater during the spring hydroperiod, while the stream sampling station exhibited greater ammonium concentrations on specific dates during the summer. The groundwater sampling station displayed the highest overall concentration of ammonium in the spring hydroperiod. Early in the spring only Taskinas Creek ammonium concentrations were greater than those observed in the groundwater. Comparison of the sampling stations revealed that groundwater concentrations of ammonium were greater than the adjacent stream during the spring hydroperiod. During the summer, significant differences were observed only on specific dates with no overall significance, unlike the previous spring. Stream ammonium concentrations during the summer were also greater than the Taskinas Creek station (Tables 2 and 3). Figure 6A and 6B present these data graphically.

Nitrate + Nitrite

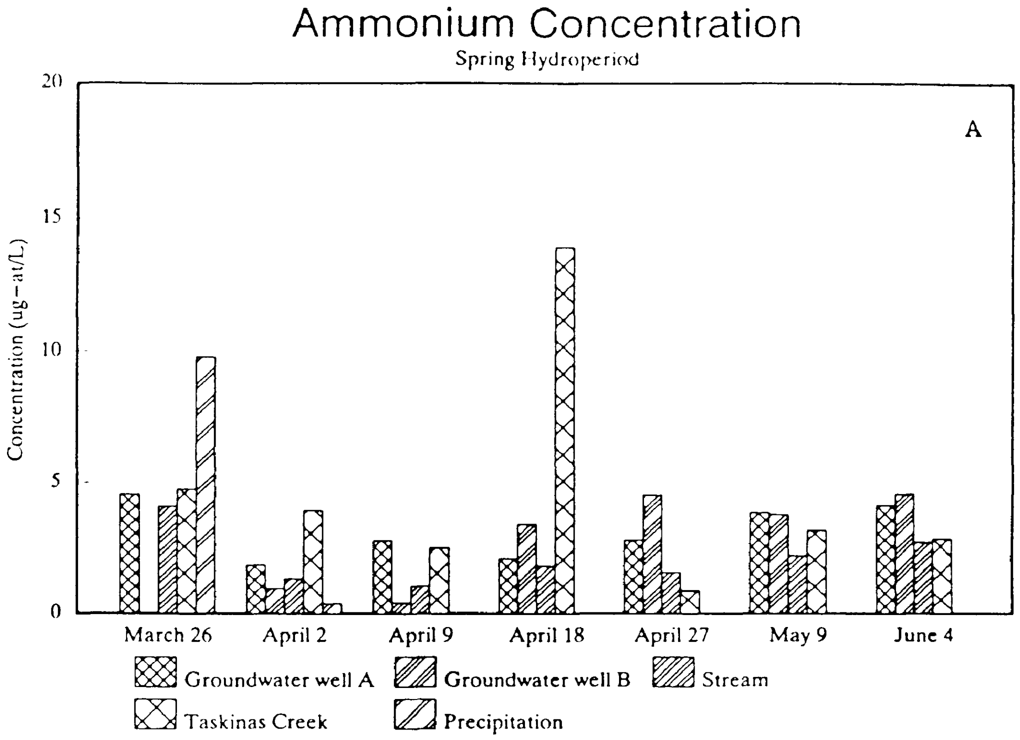
Nitrate+Nitrite concentrations in groundwater ranged from 1.46 to 3.31 ug-at/L in spring and from 1.07 to 2.78 ug-at/L in summer. Nitrite concentrations ranged from 0.24 to 0.95 ug-at/L in the spring and from 0.16 to 0.76 ug-at/L in the summer. Nitrate+nitrite concentrations in the stream ranged from 0.92 to 1.75 ug-at/L in the spring and from 1.50 to 2.56 ug-at/L in the summer. Stream nitrite concentrations ranged from 0.23 to 0.49 ug-at/L in the spring hydroperiod and from 0.25 to 0.61 ug-at/L during the summer. Taskinas Creek nitrate+nitrite concentrations ranged from 0.87 to 14.90 ug-at/L in the spring and from 0.77 to 5.84 ug-at/L in the summer hydroperiod. Nitrite ranged from 0.13 to 0.81 ug-at/L in the spring to 0.21 to 0.65 ug-at/L during the summer at the Taskinas Creek sampling station. Nitrate+nitrite concentrations observed in precipitation were 4.78 and 10.96 ug-at/L with nitrite concentrations of 0.10 and 0.16 ug-at/L respectively. Nitrate+ nitrite concentrations in groundwater were greater than those observed in the adjacent stream, but lower than those measured in Taskinas Creek downstream during the spring hydroperiod (Table 2 and 3).

Figure 6

Ammonium concentrations measured in ug-at/L.

(A: Ammonium concentrations observed during the spring 1990 hydroperiod)

(B: Ammonium concentrations observed during the summer 1990 hydroperiod)


Ammonium Concentration
Spring Hydroperiod
A
Concentration (ug-at/L)
0
5
10
15
20
March 26
April 2
April 9
April 18
April 27
May 9
June 4
Groundwater well A
Groundwater well B
Stream
Taskinas Creek
Precipitation

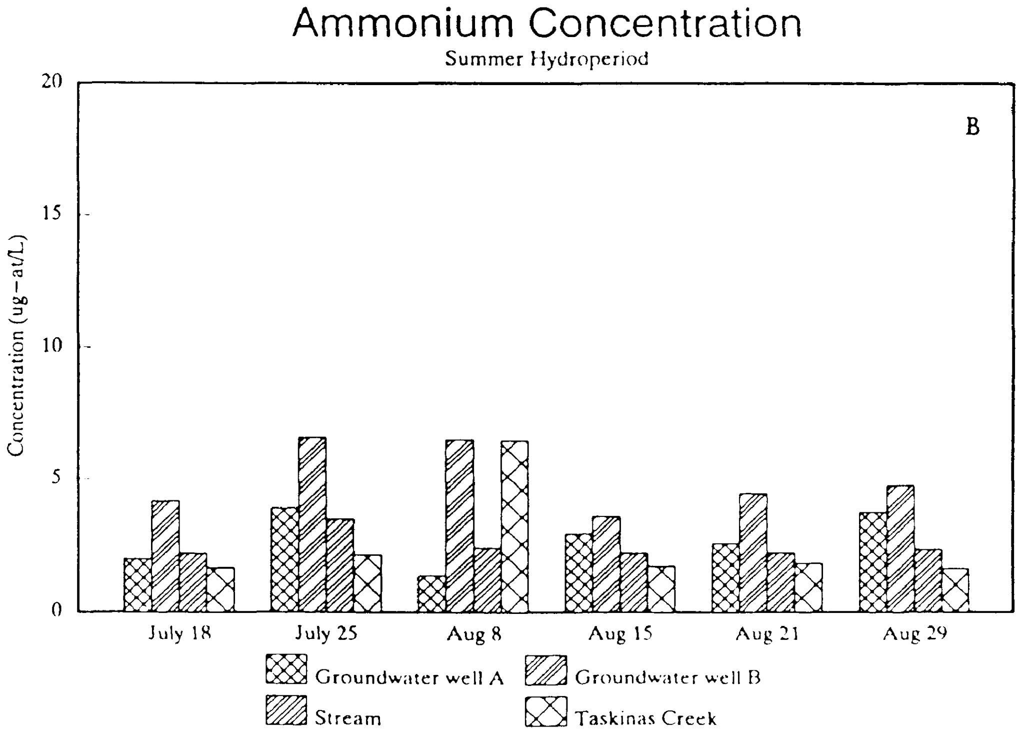

Ammonium Concentration
Summer Hydroperiod
B
Concentration (ug-at/L)
0
5
10
15
20
July 18
July 25
Aug 8
Aug 15
Aug 21
Aug 29
Groundwater well A
Groundwater well B
Stream
Taskinas Creek

Table 2: T-test for significant mean differences in nutrient concentrations by site for each sampling date, spring hydroperiod

(A= groundwater - stream; B= stream - Taskinas Ck; C= groundwater - Taskinas Ck)

Probabilities*

Date	A			B			C		
	NH4	NOx	PO4	NH4	NOx	PO4	NH4	NOx	PO4
March 26	0.099	0.013	ns	ns	0.000	0.007	ns	0.000	0.010
April 2	ns	0.002	ns	0.004	0.017	0.001	0.006	0.039	0.012
April 9	0.009	0.033	ns	0.001	0.001	0.002	ns	0.000	0.036
April 18	ns	0.052	0.004	0.000	0.000	0.017	0.000	0.000	0.002
April 27	0.058	0.036	0.069	ns	ns	0.003	0.004	0.033	0.001
May 9	0.061	ns	0.100	0.007	0.001	0.000	ns	0.007	0.017
June 4	0.019	0.018	0.063	ns	0.000	0.000	0.065	0.000	0.003
Spring Pooled (All Data)	0.003	0.000	ns	0.014	0.000	0.000	ns	0.000	0.000

T Statistic

Date	A			B			C		
	NH4	NOx	PO4	NH4	NOx	PO4	NH4	NOx	PO4
March 26	2.37	5.28			-77.22	11.66		-80.99	9.89
April 2		22.33		-7.90	-7.51	14.67	-7.04	-4.94	9.14
April 9	10.59	5.39		-16.16	-33.46	10.44		-21.34	5.15
April 18		4.23	16.48	-21.28	-37.61	-4.83	-30.05	-46.94	10.84
April 27	2.99	5.11	3.60			17.06	8.47	5.37	11.68
May 9	3.86		2.89	-6.51	-38.98	87.29		-11.62	7.51
June 4	4.65	4.76	3.80		-93.94	36.59	2.86	-84.73	18.43
Spring Pooled (All Data)	3.23	8.11		-2.66	-7.83	6.41		-6.29	7.11

*ns= not significant (p>0.10)

Table 3: T-test for significant mean differences in nutrient concentrations by site for each sampling date, summer hydroperiod

(A= groundwater - stream; B= stream - Taskinas Ck; C= groundwater - Taskinas Ck)

Probabilities*

Date		A			B			C	
	NH4	NOx	PO4	NH4	NOx	PO4	NH4	NOx	PO4
July 18	ns	ns	0.005	ns	0.000	0.000	ns	0.000	ns
July 25	ns	ns	0.021	0.023	0.001	ns	0.017	0.019	0.014
Aug 8	0.029	0.090	0.048	0.017	0.025	0.039	0.011	0.011	ns
Aug 15	ns	ns	ns	0.035	0.067	0.061	ns	0.100	0.068
Aug 21	ns	0.074	0.026	0.017	0.056	0.000	0.016	ns	0.005
Aug 29	0.008	0.066	0.015	0.064	0.007	0.003	0.005	ns	0.006
Summer Pooled (All Data)	ns	ns	ns	ns	ns	0.000	ns	ns	0.001

T Statistic

Date		A			B			C	
	NH4	NOx	PO4	NH4	NOx	PO4	NH4	NOx	PO4
July 18			-14.07		-84.31	35.84		-56.77	
July 25			4.45	6.45	29.87		7.63	7.24	8.23
Aug 8	-3.96	-3.10	-3.24	-7.55	-4.18	3.50	-9.44	-5.64	
Aug 15				5.21	3.66	3.86		2.34	2.80
Aug 21		-3.48	6.04	4.78	4.05	53.26	4.94		14.36
Aug 29	6.41	-2.84	8.09	2.86	6.68	18.32	7.34		12.46
Summer Pooled (All Data)						8.12			3.97

* ns= not significant ($p>0.10$)

Groundwater nitrate+nitrite concentrations were greater during the spring (Table 4). In comparisons by site, groundwater concentrations were greater than the adjacent stream, while Taskinas Creek concentrations were greater than both the stream and the groundwater during the spring hydroperiod. Stream nitrate+nitrite concentrations were greater in the summer hydroperiod than concentrations measured in the spring. Also during the summer, on several occasions the stream exhibited greater concentrations than the groundwater, and nearly all the Taskinas Creek observations as well. Taskinas Creek nitrate+nitrite concentrations were greater during the spring hydroperiod. Figures 7A and 7B present these data graphically.

Orthophosphate

Orthophosphate concentrations in groundwater ranged from 1.37 to 6.78 ug-at/L in the spring and from 1.44 to 12.52 ug-at/L in the summer. Stream orthophosphate concentrations observed ranged from 1.14 to 2.91 ug-at/L in the spring to 2.34 to 3.99 ug-at/L in the summer. Taskinas Creek orthophosphate concentrations ranged from 0.17 to 2.28 ug-at/L in the spring and from 0.90 to 1.81 ug-at/L in the summer and orthophosphate concentrations in precipitation were 0.67 and 0.28 ug-at/L.

Table 4: T-test for significant mean differences in nutrient concentrations by hydroperiod

A= groundwater(spring) - groundwater(summer)
B= stream(spring) - stream(summer)
C= Taskinas Ck(spring) - Taskinas Ck(summer)

Probabilities*

	A			B			C	
NH4	NOx	PO4	NH4	NOx	PO4	NH4	NOx	PO4
ns	0.000	0.046	ns	0.000	0.000	0.055	0.000	0.000

T Statistic

	A			B			C	
NH4	NOx	PO4	NH4	NOx	PO4	NH4	NOx	PO4
	4.21	-2.12		-4.32	-4.90	2.00	6.13	-4.08

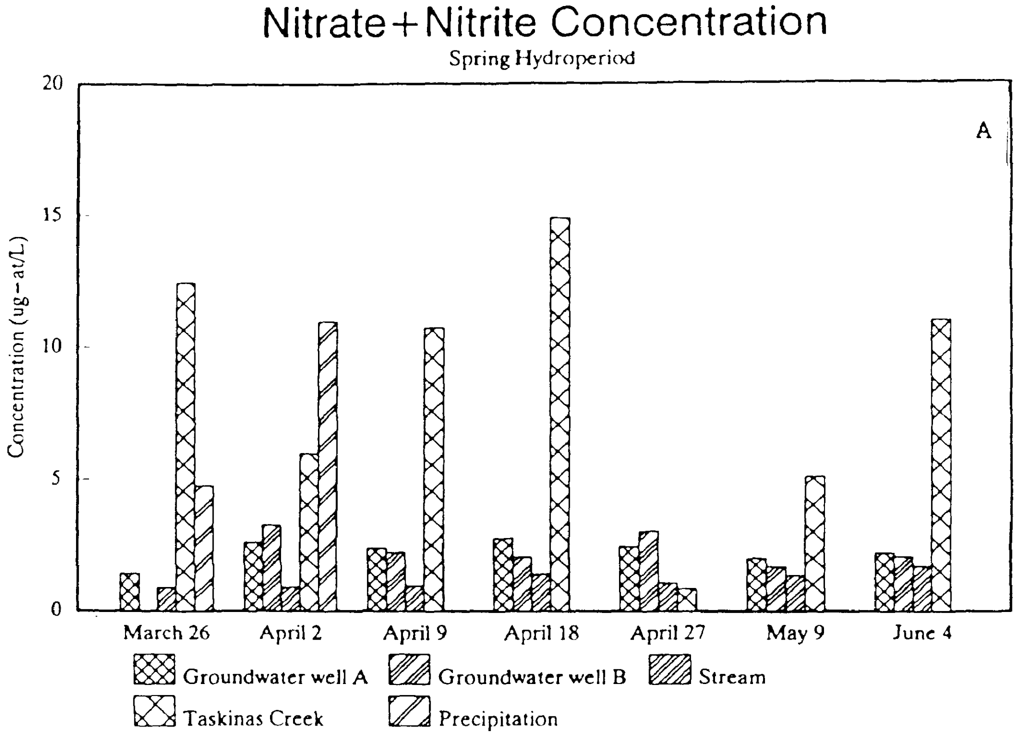
*ns= not significant (p>0.10)

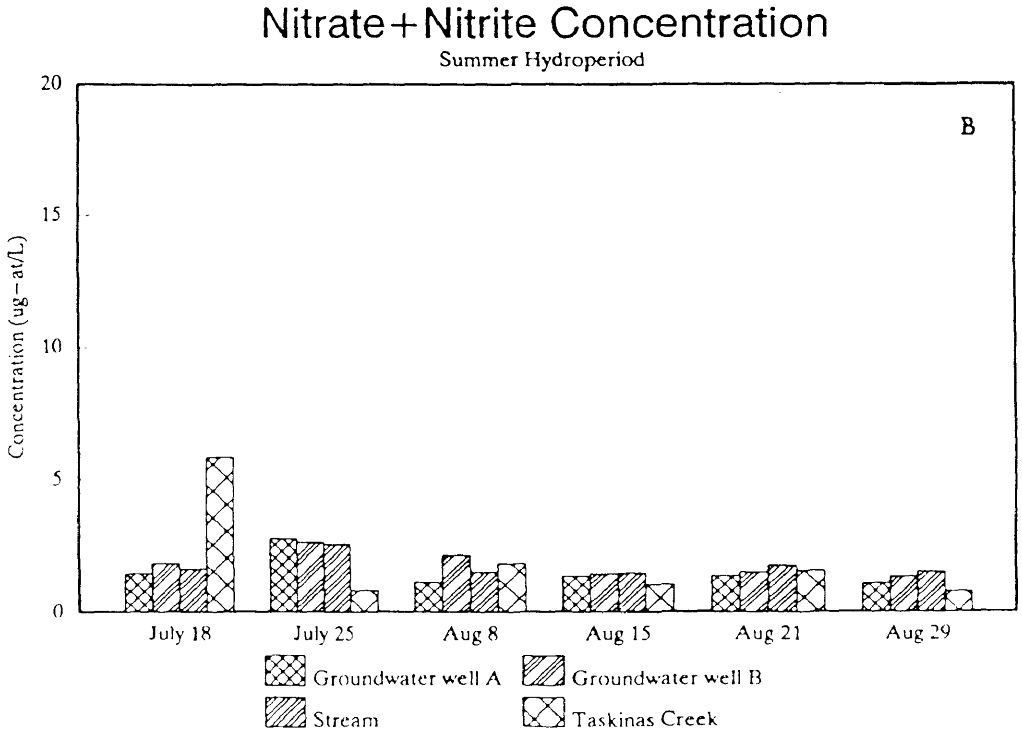
Figure 7

Nitrate+Nitrite concentrations measured in ug-at/L.

(A: Nitrate+Nitrite concentrations observed during the spring 1990 hydroperiod)

(B: Nitrate+Nitrite concentrations observed during the summer 1990 hydroperiod)


Nitrate+Nitrite Concentration
Spring Hydroperiod
A
20
15
10
5
0
Concentration (ug-at/L)
March 26
April 2
April 9
April 18
April 27
May 9
June 4
Groundwater well A
Groundwater well B
Stream
Taskinas Creek
Precipitation


Nitrate+Nitrite Concentration
Summer Hydroperiod
B
20
15
10
5
0
Concentration (ug-at/L)
July 18
July 25
Aug 8
Aug 15
Aug 21
Aug 29
Groundwater well A
Groundwater well B
Stream
Taskinas Creek

Orthophosphate concentrations in the groundwater sampling station were greater than Taskinas Creek concentrations during the spring hydroperiod with no significant difference observed in comparison with the adjacent stream (Table 2 and 3). The stream also showed greater concentrations of orthophosphate than Taskinas Creek during the spring hydroperiod. In comparing the two hydroperiods, all sampling stations showed greater orthophosphate concentrations during the summer hydroperiod (Table 4). During the summer, orthophosphate concentrations were lowest at the Taskinas Creek sampling station and generally greatest at the stream station. Figures 8A and 8B present these data graphically.

Suspended Solids

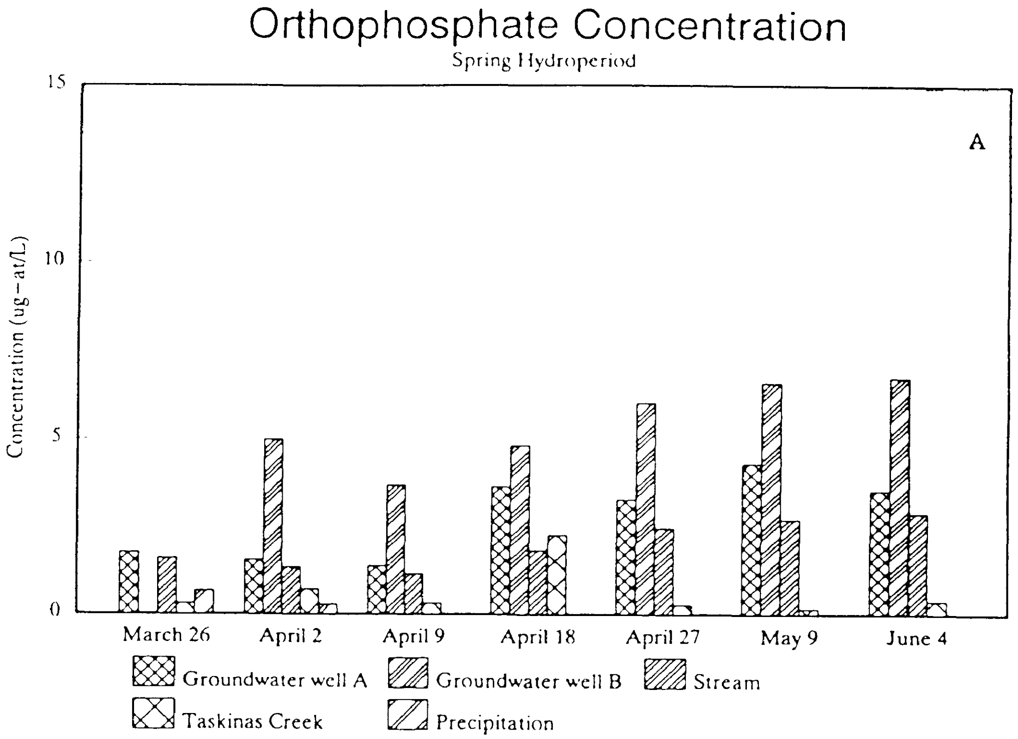
Total suspended solids were measured at the stream and Taskinas Creek sampling stations. Total suspended solids measured for the stream were greater in the summer. Suspended solids in the spring ranged from 0.4 to 30 mg/l, while summer values ranged from 9 to 19.2 mg/l. Total suspended solids in Taskinas Creek in the spring ranged from 28 to 139 mg/l and from 42.1 to 87 in the summer. Table 5 shows the suspended solids measured during both hydroperiods.

Figure 8

Orthophosphate concentrations measured in ug-at/L.

(A: Orthophosphate concentrations observed during the spring 1990 hydroperiod)

(B: Orthophosphate concentrations observed during the summer 1990 hydroperiod)


Orthophosphate Concentration
Spring Hydroperiod
A
Concentration (ug-at/L)
15
10
5
0
March 26
April 2
April 9
April 18
April 27
May 9
June 4
Groundwater well A
Groundwater well B
Stream
Taskinas Creek
Precipitation

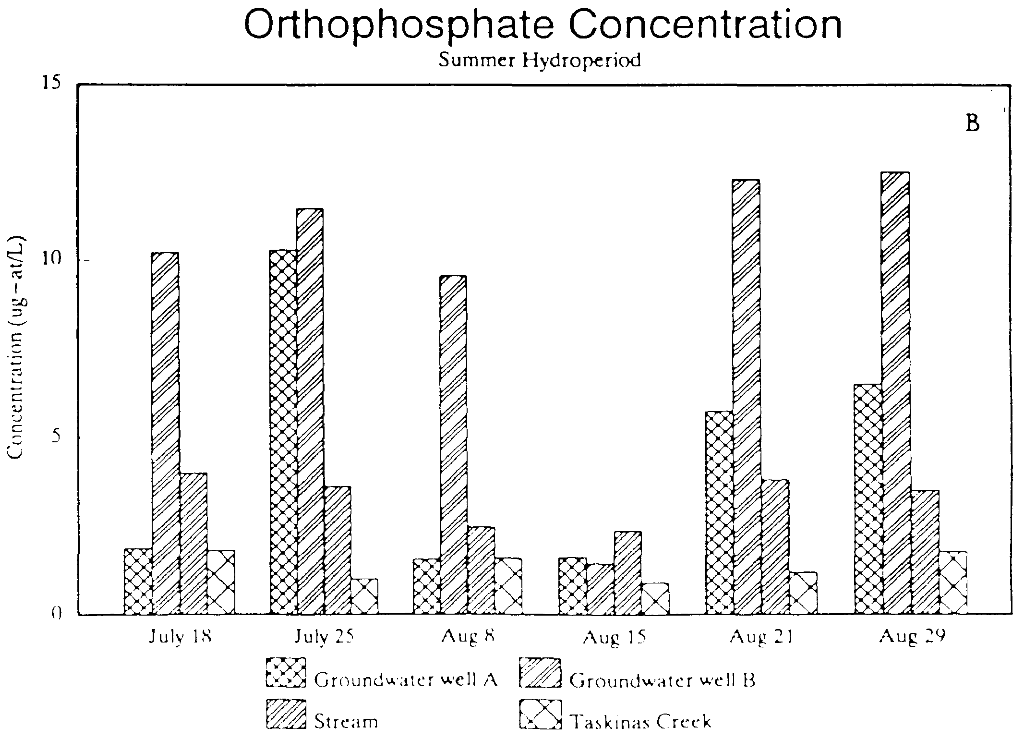

Orthophosphate Concentration
Summer Hydroperiod
B
Concentration (ug-at/L)
15
10
5
0
July 18
July 25
Aug 8
Aug 15
Aug 21
Aug 29
Groundwater well A
Groundwater well B
Stream
Taskinas Creek

Table 5: Total suspended solids measured during the spring and summer 1990 hydroperiods

Date	STREAM	TASKINAS
March 26	6.2	28.0
April 2	0.4	83.6
April 9	3.8	139.0
April 18	2.3	89.0
April 27	30.0	60.8
May 9	20.5	60.0
June 4	30.2	18.8
July 18	9.9	42.1
July 25	15.9	44.8
Aug 8	19.2	85.6
Aug 15	29.7	78.0
Aug 21	9.0	87.0
Aug 29	13.0	57.2

DISCUSSION

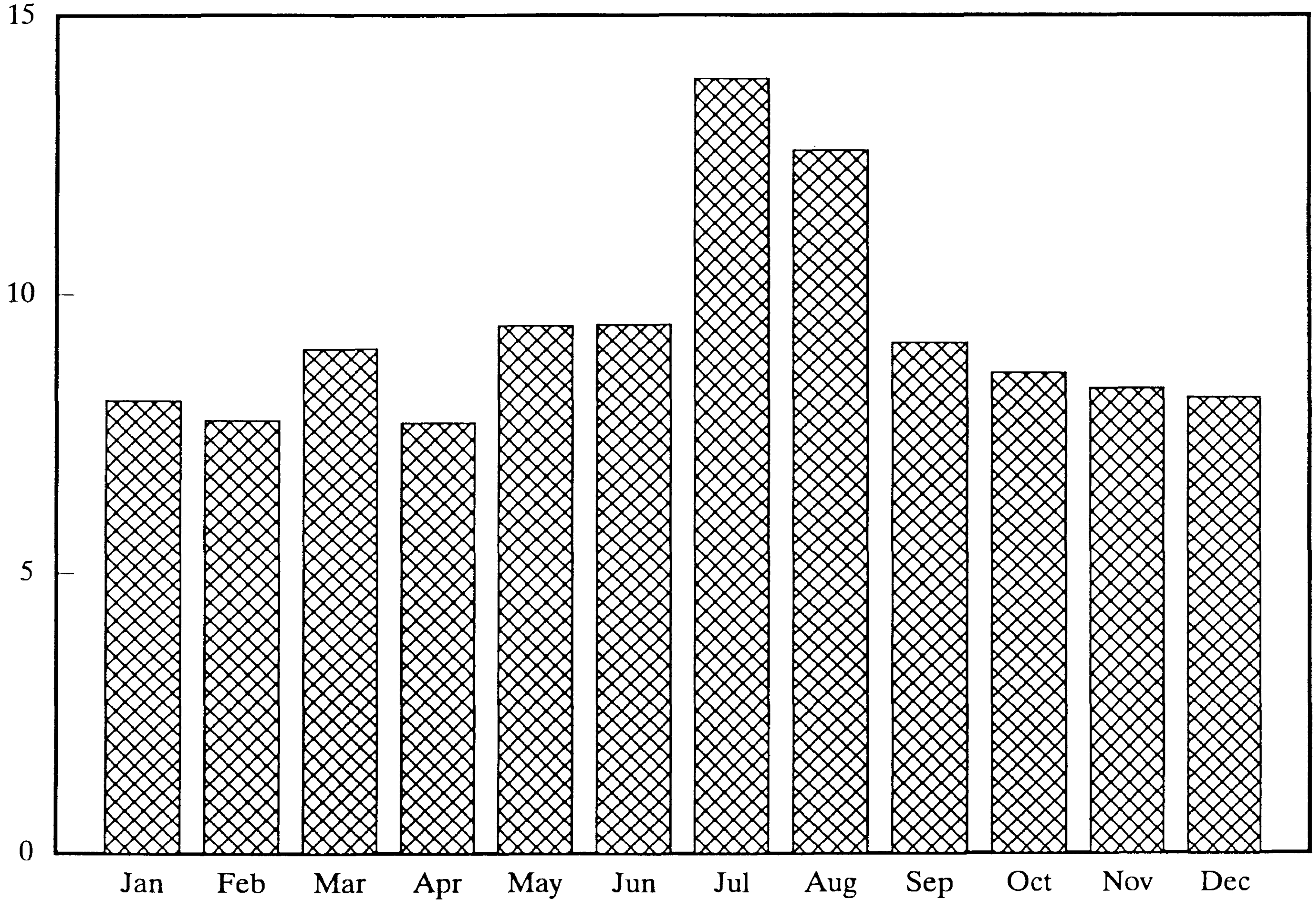
Precipitation has been shown to be an important source of nitrogen (Correll and Ford 1982), particularly during warm weather when land runoff is low. An assessment of the importance of precipitation is not possible in this study due to the lack of data and the possibility of contamination of the samples. Limitations in the precipitation collection method were discovered. The collector appeared too small to provide the amount of sample needed for analysis, although it was believed that the precipitation had an effect on the system. It appears that even small quantities of rainfall, about 1.4 cm, had an effect on the system. Nutrient levels appeared to increase after such precipitation events, but this effect requires more study. The collector needed larger surface area and could have been elevated to eliminate some of the insects and debris discovered in the water samples. The thirty year precipitation record for the region shows an increase in rainfall during the months of July and August (Figure 9), indicating that 1990 was an unusually dry year, especially so during July and August. The 1990 dry period established the fact that the headwater stream in this region is present throughout the year and not ephemeral.

Figure 9

Thirty year record mean precipitation - Upper York River Basin

Thirty Year Record Mean Precipitation

Upper York River Basin



Many of the physical characteristics of the Taskinas Creek watershed are not typical of many coastal plain environments, especially those previously reported on in the literature. The headwater streams of the watershed have small constricted valley floors located between steep-sloped ravines. These features are more characteristic of mountain headwater streams than the wide, gently sloping features normally associated with the coastal plain. Flora at the study site also show a mix of upland and coastal plain species. The ridge slopes are dominated by mountain laurel (Kalmia latifolia) and American holly (Ilex opaca), while the valley floor supports freshwater marsh species and water tolerant trees. The soils of the area are deep, and vary greatly in their composition on the ridge and hillslope.

Although several attempts were made, no surface water was collected during this study. Observations during one rain event revealed that no precipitation directly struck the surface. Precipitation was deflected by the leaves of the canopy and understory trees. At the completion of the study the collectors had only small amounts of groundwater in them. Brinson (pers. comm.) suggested that, due to the slope of the region, runoff may occur in quick events in isolated locations, and that precipitation may be completely deflected by canopy cover and reach the surface via another route other than direct striking (i.e. stemflow).

Some of the most important properties of bottomland hardwood forest soils are soil aeration, organic and clay content, and nutrient content (Mitsch and Gosselink 1986). All of these characteristics are, in turn, influenced by flooding and drying. Soil composition differed between the groundwater wells. The soils at groundwater well A were composed of a thick, organic layer atop a thin clay layer and a more porous sand layer, while the soils at groundwater well B had a very thin organic layer and a deep sand layer. Groundwater well A was shorter in length than B due to a higher water level at this spot. The wells were placed one meter apart at the same elevation on the valley floor and the differences in soil characteristics indicate a high degree of variability. Both wells recharged very quickly, but only two samples could be removed from groundwater well B. This is attributed to the deeper, more porous sand layer at groundwater well B, where the groundwater flows through rather than being retained. The samples collected from each groundwater well displayed different characteristics in appearance. Samples from groundwater well A were full of organic debris and darker in color than those collected from groundwater well B. The soils vary greatly along the base of the steep ridges in this area and the differences observed are typical for this type of topography. Differences in the nutrient concentrations between the two groundwater wells are also attributed to the soil composition at each spot. This is substantiated by studies of Harvey and Odum (1990) and Giblin and Gaines (1990). Brinson et al. (1981) also noted that clay strata or clay plugs will create a longer time lag in movement of groundwater across the gradient due to the lower transmissivity of clay sediments and may create changes in nutrient content. In order to overcome these changes in soil characteristics along the base of the hillslope a series of groundwater wells could be used to determine the scale of soil differences observed in this study.

Ammonium has been recognized as the primary form of mineralized nitrogen in wetland soils (Mitsch and Gosselink 1986). Nitrogen mineralization is "the biological transformation of organically combined nitrogen to ammonium nitrogen during organic matter degradation" (Gambrell and Patrick 1978). Ammonification occurs under both aerobic or anaerobic conditions. Under anaerobic conditions ammonium is not oxidized further and may build up in the soils. During the spring hydroperiod ammonium concentrations were greater and significantly different in the groundwater than in the adjacent stream (Table 2). This difference suggests that groundwater is an ammonium source for stream water and uptake or retention of the nutrient by the marsh community. Brinson et al. (1984) also found ammonium retention during seasonal flooding of wetland forests, primarily due to interactions between the forest floor and floodwaters. An aerobic layer is formed when the soils are exposed during the dry summer hydroperiod. Oxidation of ammonium to nitrate (nitrification) may then occur and vegetation may uptake the ion via their root systems. Summer ammonium concentrations in the groundwater were nearly equal those observed during the spring (Table 4), and showed no significant difference in comparison with the adjacent stream. This implies that the source of ammonium to the system was not affected by the changes in vegetation and precipitation regime. Ammonium concentrations in the

Rhode River Estuary were observed to be higher in the winter and spring and lower in the summer and fall (Correll and Ford 1982), similar to the variations observed in this study. Nutrient concentrations were monitored at the mouth of the Rhode River estuary and were compared with the mouth of the Taskinas Creek system. The mean summer concentration of ammonium at the mouth of the Rhode River was 36 ug-at/L while the mean ammonium concentration for Taskinas Creek during the summer was observed to be only 2.58 ug-at/L in this study. This lower concentration may be due to the overall size of the system being monitored. Taskinas Creek is a small unimpacted system, while Rhode River represents a much larger and developed system having a correspondingly larger drainage basin and nutrient loads from farms and suburban areas.

Ammonium was also measured in shallow groundwater in eastern York County by the United States Geological Survey (USGS) during the summer of 1990 (Richardson pers. comm.). Sample sites were confined to the easternmost portion of the county where soils were generally high in iron, low in dissolved oxygen, and dominated by marine sediments. Ammonium concentrations ranged from 0.71 to 53.6 ug-at/L. Groundwater ammonium concentrations in this study ranged from 1.37 to 6.57 ug-at/L indicating that the system appears to be on the lower end of the range found in this region. Many of the sites sampled by the USGS experienced non-natural imputs which implies that the system observed in this study may represent values for an unimpacted region.

Nitrate+nitrite concentrations in the groundwater were also significantly greater than adjacent stream concentrations during the spring. Nitrate is highly soluble and mobile in groundwater and may be an important source, particulary during the spring hydroperiod. Summer nitrate+nitrite concentrations were less than spring concentrations in the groundwater, but the stream showed an increase in the nutrients, reflecting an apparent export of the nutrient by the marsh community during the dryer summer hydroperiod. Correll and Ford (1982) also saw a pronounced shift from high nitrate concentrations in the spring and winter to lower concentrations in the summer and fall. The mean summer concentration for nitrate at the mouth of the Rhode River Estuary was 20 ug-at/L, while the summer nitrate mean for the Taskinas Creek site was only 1.59 ug-at/L. This difference is probably due to the differences in size, types and amounts of loadings (i.e., land use), and topography of the two systems being monitored. Johnston et. al. (1990) statistically evaluated the cumulative effect of wetlands on stream water quality and found that under high flow periods nutrients may be flushed from the system. During the summer hydroperiod, nutrient concentrations generally were higher in the stream, rather than in the groundwater, as indicated in Table 6 where pooled information consisting of hydroperiod means and standard deviations are presented. This suggests a release of nutrients by the wetland community present on the floodplain during the summer.

Table 6: Pooled data: hydroperiod means and standard deviations for constituents measured in this study

Constituent	GW-A Spring Mean	SD	GW-A Summer Mean	SD
Ammonium (ug-at/L)	3.16	0.96	2.76	0.90
Nitrate+Nitrite (ug-at/L)	2.31	0.42	1.53	0.58
Total DIN (ug-at/L)	5.47	0.62	4.29	1.29
Orthophosphate (ug-at/L)	2.78	1.11	4.59	3.24
N:P Ratio	1.97		0.93	
Total Suspended Solids (mg/l)				
Salinity (ppt)	0.00		1.50	0.76

Constituent	GW-B Spring Mean	SD	GW-B Summer Mean	SD
Ammonium (ug-at/L)	2.53	1.85	5.00	1.13
Nitrate+ Nitrite (ug-at/L)	2.08	1.00	1.82	0.47
Total DIN (ug-at/L)	4.60	2.39	6.81	1.54
Orthophosphate (ug-at/L)	4.71	2.17	9.59	3.79
N:P Ratio	0.98		0.71	
Total Suspended Solids (mg/l)				
Salinity (ppt)	0.00		1.67	0.94

Constituent	STREAM Spring Mean	SD	STREAM Summer Mean	SD
Ammonium (ug-at/L)	2.11	0.95	2.49	0.46
Nitrate+ Nitrite (ug-at/L)	1.22	0.30	1.74	0.38
Total DIN (ug-at/L)	3.33	1.03	4.23	0.82
Orthophosphate (ug-at/L)	2.00	0.65	3.28	0.64
N:P Ratio	1.66		1.29	
Total Suspended Solids (mg/l)	13.34	12.21	16.12	6.99
Salinity (ppt)	0.07	0.17	1.50	0.76

Constituent	TASKINAS Spring Mean	SD	TASKINAS Summer Mean	SD
Ammonium (ug-at/L)	4.57	3.96	2.58	1.74
Nitrate+ Nitrite (ug-at/L)	8.74	4.53	1.98	1.77
Total DIN (ug-at/L)	13.30	7.79	4.55	2.40
Orthophosphate (ug-at/L)	0.63	0.69	1.37	0.36
N:P Ratio	21.10		3.32	
Total Suspended Solids (mg/l)	68.46	37.53	65.78	18.56
Salinity (ppt)	3.83	2.81	8.33	4.03

The USGS also sampled nitrate+nitrite during the summer of 1990 and obtained concentrations around 7.15 ug-at/L throughout the study region. Nitrate+nitrite concentrations ranged from 1.07 to 2.78 ug-at/L in the groundwater during the summer hydroperiod of this study. Again, this suggests that the Taskinas system is on the lower end of the concentrations observed for this region and may be indicative of the unimpacted nature and the unique topography of the study site.

Orthophosphate concentrations were higher in groundwater than the stream on several dates during the spring hydroperiod. In a pilot study to determine the efficiency of forested buffer strips (Hershner 1987), orthophosphate was measured in shallow groundwater at a site in the York River basin. Average orthophosphate concentrations ranged from 0.11 to 2.55 ug-at/L in the forested buffer strip, 0.44 to 1.75 ug-at/L at the marsh/upland boundary and 3.85 to 7.58 ug-at/L in the marsh. The concentrations for the marsh/upland site are similar to the concentrations observed during the same hydroperiod in this study, and appear to be indicative of the conditions expected at the marsh/upland interface in this region.

Phosphorus has a higher affinity for clay particles than it does for sand or silt. It may be adsorbed to clay particles which may then be released during the exposed conditions of the summer hydroperiod. Other studies have shown that a considerable portion of the phosphorus transported to riparian wetlands is sorbed to clay particles and sedimentation provides sustained supplies (Brinson et al. 1981; Mitsch and Gosselink 1986). Summer concentrations for both the groundwater and stream were greater than those measured during the spring, with groundwater concentrations significantly greater than in the stream, indicating a probable groundwater source and uptake by the marsh community (Figure 8). Release of phosphorus from the exposed clay particles during the dry hydroperiod may provide a source for the higher groundwater values exhibited in this study. Several studies noted that the bulk of phosphorus input to wetland systems is sorbed to fine particles and trapped in floodplain systems (Brinson et al. 1984; Johnston et al. 1984; Whigham et al. 1988). The increase in orthophosphate observed at both sampling stations in this study during the summer appears to be due to a release of the nutrient by the clay particles transported to the site during the spring hydroperiod, the decomposition of organic material, and changes in the vegetative structure of the marsh community, which may serve to uptake a portion of the nutrient during the growing season. This increase in orthophosphate during the summer warrants more investigation.

Taskinas Creek exhibited wide variations in concentrations due to tidal action and mixing with York River waters. Ammonium and nitrate+nitrite concentrations were higher during the spring, with only orthophosphate higher during the summer. For comparison, these data were compared to water quality data available from the Virginia Water Control Board (1989) for the year 1987. Ammonium concentrations for the York River were 8.57 ug-at/L for the spring, while pooled Taskinas Creek mean values for this study were 4.57 ug-at/L for the spring hydroperiod. The marsh system downstream may be a sink for this constituent in the spring. Spring nitrate+nitrite concentrations for the York River were 7.14 ug-at/L, while values for this study at Taskinas Creek were 8.74 ug-at/L. Indicating that the Taskinas Creek may be a source of nitrate+nitrite in the spring. Summer ammonium values were also greater for the York River with values remaining at 8.57 ug-at/L, while the Taskinas Creek concentrations fell to 2.58 ug-at/L, inferring that uptake continues through the summer season. Nitrate + nitrite concentrations were 6.43 ug-at/L in the York River during the summer and concentrations observed during the summer in this study at Taskinas Creek were also lower, with a pooled summer mean of 1.97 ug-at/L, showing a shift to uptake of the nutrient by the Taskinas Creek system.

CONCLUSIONS/SUMMARY

Nutrient concentrations in the Taskinas Creek watershed are lower than those measured in nearby York County, and may be indicative of the unimpacted nature of the region. The results of this study also indicate that groundwater presents an important nutrient source, particularly during the spring hydroperiod when the system appears to respond to precipitation and increased runoff. Spring groundwater is an important source of ammonium and nitrogen to the system at sampling station one. Groundwater is an important source of orthophosphate during both the spring and summer at sampling station one. Variability discovered in soil types and nutrient concentrations along the base of the hillslope indicate the need for more intense groundwater monitoring. The increase in orthophosphate seen during the summer hydroperiod also warrants further investigation.

The marsh community on the stream floodplain indicates a possible uptake of all nutrients measured during the spring and a release of these nutrients during the summer hydroperiod and the implications of these findings also need to be investigated.

Sampling station two located on Taskinas Creek showed the greatest variation, presumably due to York River influence. The marsh system downstream appeared to uptake ammonium during both the spring and summer, while a shift was noted in nitrate+nitrite concentrations. During the spring Taskinas Creek appeared to be a source of these nutrients but summer concentrations implied a shift to a sink of these same nutrients.

APPENDIX A

Raw data tables presenting nutrient concentrations observed during both the spring and summer hydroperiods, 1990.

Table 7: Ammonium concentrations in ug-at/L during the spring 1990 hydroperiod

Date	Location				
	GW-A 1	GW-A 2	GW-A 3	MEAN	STD
March 26	4.31	4.84	4.52	4.56	0.22
April 2	1.62	1.69	2.24	1.85	0.28
April 9	3.01	2.87	2.50	2.79	0.22
April 18	2.52	1.62	2.12	2.09	0.37
April 27	2.73	3.19	2.52	2.81	0.28
May 9	4.56	3.92	3.10	3.86	0.60
June 4	4.62	4.05	3.73	4.13	0.37
	GW-B 1	GW-B 2		MEAN	STD
March 26	0.00	0.00		0.00	0.00
April 2	0.94	0.95		0.95	0.00
April 9	0.42	0.40		0.41	0.01
April 18	3.36	3.43		3.40	0.04
April 27	4.32	4.75		4.54	0.22
May 9	3.98	3.57		3.78	0.21
June 4	3.37	5.81		4.59	1.22
	STREAM 1	STREAM 2	STREAM 3	MEAN	STD
March 26	4.30	4.09	3.86	4.08	0.18
April 2	1.79	1.23	0.96	1.33	0.35
April 9	0.94	1.16	1.04	1.05	0.09
April 18	1.49	2.76	1.17	1.81	0.69
April 27	1.10	2.29	1.32	1.57	0.52
May 9	2.05	2.27	2.29	2.20	0.11
June 4	2.43	2.99	2.71	2.71	0.23
	TC 1	TC 2	TC 3	MEAN	STD
March 26	6.55	3.26	4.43	4.75	1.36
April 2	3.51	4.26	4.02	3.93	0.31
April 9	2.62	2.40	2.49	2.50	0.09
April 18	13.41	13.81	14.42	13.88	0.42
April 27	0.90	1.07	0.68	0.88	0.16
May 9	3.30	3.34	2.93	3.19	0.18
June 4	3.54	2.27	2.69	2.83	0.53
	PREC 1	PREC 2	PREC 3	MEAN	STD
March 26	20.76	0.00	0.00	6.92	9.79
April 2	5.62	6.50	6.35	6.16	0.38

Table 8: Ammonium concentrations in ug-at/L during the summer 1990 hydroperiod

Date	Location				
	GW-A 1	GW-A 2	GW-A 3	MEAN	STD
July 18	2.11	1.80	2.09	2.00	0.14
July 25	4.14	4.12	3.47	3.91	0.31
Aug 8	1.08	1.74	1.30	1.37	0.27
Aug 15	2.55	2.23	4.04	2.94	0.79
Aug 21	2.85	2.49	2.41	2.58	0.19
Aug 29	3.92	3.93	3.39	3.75	0.25
	GW-B 1	GW-B 2		MEAN	STD
July 18	4.06	4.26		4.16	0.10
July 25	6.41	6.72		6.57	0.15
Aug 8	5.91	7.02		6.47	0.56
Aug 15	3.43	3.75		3.59	0.16
Aug 21	4.77	4.12		4.45	0.32
Aug 29	4.63	4.86		4.75	0.11
	STREAM 1	STREAM 2	STREAM 3	MEAN	STD
July 18	2.31	2.23	2.12	2.22	0.08
July 25	3.45	3.19	3.87	3.50	0.28
Aug 8	2.76	2.37	2.14	2.42	0.26
Aug 15	2.27	2.06	2.37	2.23	0.13
Aug 21	2.32	2.16	2.22	2.23	0.07
Aug 29	2.35	2.58	2.16	2.36	0.17
	TC 1	TC 2	TC 3	MEAN	STD
July 18	1.33	2.03	1.65	1.67	0.29
July 25	2.25	2.03	2.19	2.16	0.09
Aug 8	5.54	6.51	7.27	6.44	0.71
Aug 15	1.79	1.72	1.69	1.73	0.04
Aug 21	1.91	1.69	1.89	1.83	0.10
Aug 29	1.42	2.08	1.38	1.63	0.32

Table 9: Nitrate concentrations in ug-at/L during the spring 1990 hydroperiod

Date	Location				
	GW-A 1	GW-A 2	GW-A 3	MEAN	STD
March 26	1.18	1.17	1.05	1.13	0.06
April 2	1.92	1.81	1.78	1.84	0.06
April 9	1.51	1.73	2.40	1.88	0.38
April 18	2.72	2.48	2.21	2.47	0.21
April 27	1.80	2.65	1.65	2.03	0.44
May 9	2.05	1.63	1.36	1.68	0.28
June 4	1.60	1.62	1.72	1.65	0.05
	GW-B 1	GW-B 2		MEAN	STD
March 26	0.00	0.00		0.00	0.00
April 2	2.28	2.45		2.37	0.08
April 9	1.61	2.10		1.86	0.24
April 18	1.71	2.01		1.86	0.15
April 27	2.03	2.22		2.13	0.10
May 9	1.24	1.28		1.26	0.02
June 4	1.70	1.93		1.82	0.11
	STREAM 1	STREAM 2	STREAM 3	MEAN	STD
March 26	0.78	0.57	0.59	0.65	0.10
April 2	0.69	0.75	0.62	0.69	0.05
April 9	0.83	0.76	0.65	0.75	0.07
April 18	0.93	0.87	1.75	1.18	0.40
April 27	0.72	0.70	0.70	0.71	0.01
May 9	1.04	0.96	0.92	0.97	0.05
June 4	1.21	1.42	1.14	1.26	0.12
	TC 1	TC 2	TC 3	MEAN	STD
March 26	12.00	12.26	12.44	12.23	0.18
April 2	4.42	5.92	6.66	5.67	0.93
April 9	10.87	9.98	10.78	10.54	0.40
April 18	13.99	13.76	14.53	14.09	0.32
April 27	0.62	0.60	1.00	0.74	0.18
May 9	5.02	4.83	4.71	4.85	0.13
June 4	10.34	10.46	10.27	10.36	0.08
	PREC 1	PREC 2	PREC 3	MEAN	STD
March 26	14.04	0.00	0.00	4.68	6.62
April 2	11.41	10.84	10.15	10.80	0.52

Table 10: Nitrate concentrations in ug-at/L during the summer 1990 hydroperiod

Date	**Location**				
	GW-A 1	GW-A 2	GW-A 3	MEAN	STD
July 18	0.99	1.21	0.88	1.03	0.14
July 25	2.66	1.70	2.35	2.24	0.40
Aug 8	1.08	1.10	0.74	0.97	0.17
Aug 15	1.29	1.27	1.08	1.21	0.09
Aug 21	0.97	1.22	1.27	1.15	0.13
Aug 29	0.61	0.77	1.03	0.80	0.17
	GW-B 1	GW-B 2		MEAN	STD
July 18	1.41	1.31		1.36	0.05
July 25	1.41	2.38		1.90	0.48
Aug 8	1.49	1.69		1.59	0.10
Aug 15	0.88	0.89		0.89	0.00
Aug 21	0.89	1.05		0.97	0.08
Aug 29	0.74	0.86		0.80	0.06
	STREAM 1	STREAM 2	STREAM 3	MEAN	STD
July 18	1.12	1.30	1.24	1.22	0.07
July 25	1.98	1.91	1.97	1.95	0.03
Aug 8	1.31	1.18	1.24	1.24	0.05
Aug 15	1.23	1.19	1.20	1.21	0.02
Aug 21	1.39	1.38	1.26	1.34	0.06
Aug 29	1.16	1.28	1.13	1.19	0.06
	TC 1	TC 2	TC 3	MEAN	STD
July 18	5.17	5.27	5.13	5.19	0.06
July 25	0.61	0.57	0.60	0.59	0.02
Aug 8	1.43	1.54	1.48	1.48	0.04
Aug 15	0.61	0.60	0.84	0.68	0.11
Aug 21	1.05	1.08	1.05	1.06	0.01
Aug 29	0.68	0.49	0.44	0.54	0.10

Table 11: Nitrite concentrations in ug-at/L during the spring 1990 hydroperiod

Date	Location				
	GW-A 1	GW-A 2	GW-A 3	MEAN	STD
March 26	0.38	0.30	0.31	0.33	0.04
April 2	0.87	0.74	0.85	0.82	0.06
April 9	0.63	0.47	0.56	0.55	0.07
April 18	0.36	0.34	0.36	0.35	0.01
April 27	0.53	0.42	0.45	0.47	0.05
May 9	0.45	0.38	0.27	0.37	0.07
June 4	0.54	0.79	0.51	0.61	0.13
	GW-B 1	GW-B 2		MEAN	STD
March 26	0.00	0.00		0.00	0.00
April 2	0.94	0.95		0.95	0.00
April 9	0.42	0.40		0.41	0.01
April 18	0.21	0.26		0.24	0.02
April 27	1.02	0.87		0.95	0.07
May 9	0.42	0.49		0.46	0.03
June 4	0.30	0.29		0.30	0.00
	STREAM 1	STREAM 2	STREAM 3	MEAN	STD
March 26	0.31	0.27	0.24	0.27	0.03
April 2	0.27	0.23	0.26	0.25	0.02
April 9	0.24	0.23	0.23	0.23	0.00
April 18	0.26	0.27	0.28	0.27	0.01
April 27	0.39	0.38	0.38	0.38	0.00
May 9	0.43	0.43	0.43	0.43	
June 4	0.44	0.47	0.56	0.49	0.05
	TC 1	TC 2	TC 3	MEAN	STD
March 26	0.20	0.24	0.17	0.20	0.03
April 2	0.30	0.37	0.34	0.34	0.03
April 9	0.22	0.20	0.20	0.21	0.01
April 18	0.84	0.82	0.77	0.81	0.03
April 27	0.12	0.14	0.13	0.13	0.01
May 9	0.29	0.32	0.29	0.30	0.01
June 4	0.70	0.72	0.68	0.70	0.02
	PREC 1	PREC 2	PREC 3	MEAN	STD
March 26	0.30	0.00	0.00	0.10	0.14
April 2	0.20	0.17	0.12	0.16	0.03

Table 12: Nitrite concentrations in ug-at/L during the summer 1990 hydroperiod

Date	Location				
	GW-A 1	GW-A 2	GW-A 3	MEAN	STD
July 18	0.42	0.38	0.50	0.43	0.05
July 25	0.54	0.57	0.53	0.55	0.02
Aug 8	0.10	0.19	0.19	0.16	0.04
Aug 15	0.16	0.16	0.13	0.15	0.01
Aug 21	0.21	0.22	0.23	0.22	0.01
Aug 29	0.24	0.27	0.29	0.27	0.02
	GW-B 1	GW-B 2		MEAN	STD
July 18	0.47	0.51		0.49	0.02
July 25	0.74	0.77		0.76	0.02
Aug 8	0.48	0.66		0.57	0.09
Aug 15	0.54	0.57		0.56	0.01
Aug 21	0.54	0.51		0.53	0.02
Aug 29	0.52	0.49		0.51	0.01
	STREAM 1	STREAM 2	STREAM 3	MEAN	STD
July 18	0.47	0.39	0.40	0.42	0.04
July 25	0.55	0.57	0.70	0.61	0.07
Aug 8	0.22	0.22	0.32	0.25	0.05
Aug 15	0.29	0.26	0.26	0.27	0.01
Aug 21	0.42	0.40	0.40	0.41	0.01
Aug 29	0.38	0.35	0.24	0.32	0.06
	TC 1	TC 2	TC 3	MEAN	STD
July 18	0.66	0.64	0.64	0.65	0.01
July 25	0.22	0.21	0.21	0.21	0.00
Aug 8	0.28	0.36	0.44	0.36	0.07
Aug 15	0.31	0.30	0.43	0.35	0.06
Aug 21	0.49	0.49	0.52	0.50	0.01
Aug 29	0.25	0.20	0.24	0.23	0.02

Table 13: Nitrate+Nitrite concentrations in ug-at/L during the spring 1990 hydroperiod

Date	Location				
	GW-A 1	GW-A 2	GW-A 3	MEAN	STD
March 26	1.56	1.47	1.36	1.46	0.08
April 2	2.79	2.55	2.63	2.66	0.10
April 9	2.14	2.20	2.96	2.43	0.37
April 18	3.08	2.82	2.57	2.82	0.21
April 27	2.33	3.07	2.10	2.50	0.41
May 9	2.50	2.01	1.63	2.05	0.36
June 4	2.14	2.41	2.23	2.26	0.11

	GW-B 1	GW-B 2		MEAN	STD
March 26	0.00	0.00		0.00	0.00
April 2	3.22	3.40		3.31	0.09
April 9	2.03	2.50		2.27	0.23
April 18	1.92	2.27		2.10	0.17
April 27	3.05	3.09		3.07	0.02
May 9	1.66	1.77		1.72	0.05
June 4	2.00	2.22		2.11	0.11

	STREAM 1	STREAM 2	STREAM 3	MEAN	STD
March 26	1.09	0.84	0.83	0.92	0.12
April 2	0.96	0.98	0.88	0.94	0.04
April 9	1.07	0.99	0.88	0.98	0.08
April 18	1.19	1.14	2.03	1.45	0.41
April 27	1.11	1.08	1.08	1.09	0.01
May 9	1.47	1.39	1.35	1.40	0.05
June 4	1.65	1.89	1.70	1.75	0.10

	TC 1	TC 2	TC 3	MEAN	STD
March 26	12.20	12.50	12.61	12.44	0.17
April 2	4.72	6.29	7.00	6.00	0.95
April 9	11.09	10.18	10.98	10.75	0.41
April 18	14.83	14.58	15.30	14.90	0.30
April 27	0.74	0.74	1.13	0.87	0.18
May 9	5.31	5.15	5.00	5.15	0.13
June 4	11.04	11.18	10.95	11.06	0.09

	PREC 1	PREC 2	PREC 3	MEAN	STD
March 26	14.34	0.00	0.00	4.78	6.76
April 2	11.61	11.01	10.27	10.96	0.55

Table 14: Nitrate+Nitrite concentrations in ug-at/L during the summer 1990 hydroperiod

Date	Location				
	GW-A 1	GW-A 2	GW-A 3	MEAN	STD
July 18	1.41	1.59	1.38	1.46	0.09
July 25	3.20	2.27	2.88	2.78	0.39
Aug 8	1.18	1.29	0.93	1.13	0.15
Aug 15	1.45	1.43	1.21	1.36	0.11
Aug 21	1.18	1.44	1.50	1.37	0.14
Aug 29	0.85	1.04	1.32	1.07	0.19
	GW-B 1	GW-B 2	GW-B 3	MEAN	STD
July 18	1.88	1.82		1.85	0.03
July 25	2.15	3.15		2.65	0.50
Aug 8	1.97	2.35		2.16	0.19
Aug 15	1.42	1.46		1.44	0.02
Aug 21	1.43	1.56		1.50	0.06
Aug 29	1.26	1.35		1.31	0.04
	STREAM 1	STREAM 2	STREAM 3	MEAN	STD
July 18	1.59	1.69	1.64	1.64	0.04
July 25	2.53	2.48	2.67	2.56	0.08
Aug 8	1.53	1.40	1.56	1.50	0.07
Aug 15	1.52	1.45	1.46	1.48	0.03
Aug 21	1.81	1.78	1.66	1.75	0.06
Aug 29	1.54	1.63	1.37	1.51	0.11
	TC 1	TC 2	TC 3	MEAN	STD
July 18	5.83	5.91	5.77	5.84	0.06
July 25	0.83	0.78	0.81	0.81	0.02
Aug 8	1.71	1.90	1.92	1.84	0.09
Aug 15	0.92	0.90	1.27	1.03	0.17
Aug 21	1.54	1.57	1.57	1.56	0.01
Aug 29	0.93	0.69	0.68	0.77	0.12

Table 15: Total DIN concentrations in ug-at/L during the spring 1990 hydroperiod

Date	Location				
	GW-A 1	GW-A 2	GW-A 3	MEAN	STD
March 26	5.87	6.31	5.88	6.02	0.21
April 2	4.41	4.24	4.87	4.51	0.27
April 9	5.15	5.07	5.46	5.23	0.17
April 18	5.60	4.44	4.69	4.91	0.50
April 27	5.06	6.26	4.62	5.31	0.69
May 9	7.06	5.93	4.73	5.91	0.95
June 4	6.76	6.46	5.96	6.39	0.33
	GW-B 1	GW-B 2		MEAN	STD
March 26	0.00	0.00		0.00	0.00
April 2	4.16	4.35		4.26	0.09
April 9	2.45	2.90		2.68	0.22
April 18	5.28	5.70		5.49	0.21
April 27	7.37	7.84		7.61	0.23
May 9	5.64	5.34		5.49	0.15
June 4	5.37	8.03		6.70	1.33
	STREAM 1	STREAM 2	STREAM 3	MEAN	STD
March 26	5.39	4.93	4.69	5.00	0.29
April 2	2.75	2.21	1.84	2.27	0.37
April 9	2.01	2.15	1.92	2.03	0.09
April 18	2.68	3.90	3.20	3.26	0.50
April 27	2.21	3.37	2.40	2.66	0.51
May 9	3.52	3.66	3.64	3.61	0.06
June 4	4.08	4.88	4.41	4.46	0.33
	TC 1	TC 2	TC 3	MEAN	STD
March 26	18.75	15.76	17.04	17.18	1.22
April 2	8.23	10.55	11.02	9.93	1.22
April 9	13.71	12.58	13.47	13.25	0.49
April 18	28.24	28.39	29.72	28.78	0.67
April 27	1.64	1.81	1.81	1.75	0.08
May 9	8.61	8.49	7.93	8.34	0.30
June 4	14.58	13.45	13.64	13.89	0.49
	PREC 1	PREC 2	PREC 3	MEAN	STD
March 26	35.10	0.00	0.00	11.70	16.55
April 2	17.23	17.51	16.62	17.12	0.37

Table 16: Total DIN concentrations in ug-at/L during the summer 1990 hydroperiod

Date	Location				
	GW-A 1	GW-A 2	GW-A 3	MEAN	STD
July 18	3.52	3.39	3.47	3.46	0.05
July 25	7.34	6.39	6.35	6.69	0.46
Aug 8	2.26	3.03	2.23	2.51	0.37
Aug 15	4.00	3.66	5.25	4.30	0.68
Aug 21	4.03	3.93	3.91	3.96	0.05
Aug 29	4.77	4.97	4.71	4.82	0.11
	GW-B 1	GW-B 2	GW-B 3	MEAN	STD
July 18	5.94	6.08		6.01	0.07
July 25	8.56	9.87		9.22	0.65
Aug 8	7.88	9.37		8.63	0.74
Aug 15	4.85	5.21		5.03	0.18
Aug 21	6.20	5.68		5.94	0.26
Aug 29	5.89	6.21		6.05	0.16
	STREAM 1	STREAM 2	STREAM 3	MEAN	STD
July 18	3.90	3.92	3.76	3.86	0.07
July 25	5.98	5.67	6.54	6.06	0.36
Aug 8	4.20	3.77	3.70	3.89	0.22
Aug 15	3.79	3.51	3.83	3.71	0.14
Aug 21	4.13	3.94	3.88	3.98	0.11
Aug 29	3.89	4.21	3.53	3.88	0.28
	TC 1	TC 2	TC 3	MEAN	STD
July 18	7.16	7.94	7.42	7.51	0.32
July 25	3.08	2.81	3.00	2.96	0.11
Aug 8	7.25	8.41	9.19	8.28	0.80
Aug 15	2.71	2.62	2.96	2.76	0.14
Aug 21	3.45	3.26	3.46	3.39	0.09
Aug 29	2.35	2.77	2.06	2.39	0.29

Table 17: Orthophosphate concentrations in ug-at/L during the spring 1990 hydroperiod

Date	Location				
	GW-A 1	GW-A 2	GW-A 3	MEAN	STD
March 26	2.05	1.66	1.57	1.76	0.21
April 2	1.59	1.67	1.38	1.55	0.12
April 9	0.98	1.59	1.55	1.37	0.28
April 18	3.49	3.84	3.66	3.66	0.14
April 27	3.64	3.38	2.87	3.30	0.32
May 9	4.84	4.91	3.22	4.32	0.78
June 4	3.26	3.60	3.83	3.56	0.23
	GW-B 1	GW-B 2		MEAN	STD
March 26	0.00	0.00		0.00	0.00
April 2	4.84	5.13		4.99	0.14
April 9	3.63	3.74		3.69	0.05
April 18	5.00	4.67		4.84	0.17
April 27	5.19	6.90		6.05	0.85
May 9	6.23	7.01		6.62	0.39
June 4	6.71	6.84		6.78	0.06
	STREAM 1	STREAM 2	STREAM 3	MEAN	STD
March 26	1.47	1.49	1.81	1.59	0.16
April 2	1.39	1.30	1.29	1.33	0.04
April 9	1.24	1.08	1.11	1.14	0.07
April 18	1.93	1.79	1.80	1.84	0.06
April 27	2.52	2.47	2.45	2.48	0.03
May 9	2.73	2.72	2.73	2.73	0.00
June 4	2.81	2.94	2.97	2.91	0.07
	TC 1	TC 2	TC 3	MEAN	STD
March 26	0.31	0.31	0.27	0.30	0.02
April 2	0.73	0.76	0.67	0.72	0.04
April 9	0.43	0.27	0.22	0.31	0.09
April 18	2.35	2.36	2.12	2.28	0.11
April 27	0.40	0.00	0.37	0.26	0.18
May 9	0.22	0.18	0.12	0.17	0.04
June 4	0.48	0.34	0.33	0.38	0.07
	PREC 1	PREC 2	PREC 3	MEAN	STD
March 26	2.01	0.00	0.00	0.67	0.95
April 2	0.28	0.40	0.17	0.28	0.09

Table 18: Orthophosphate concentrations in ug-at/L during the summer 1990 hydroperiod

Date	Location				
	GW-A 1	GW-A 2	GW-A 3	MEAN	STD
July 18	2.12	1.82	1.63	1.86	0.20
July 25	11.23	11.61	8.05	10.30	1.60
Aug 8	2.01	1.42	1.26	1.56	0.32
Aug 15	1.93	1.67	1.20	1.60	0.30
Aug 21	5.09	6.03	6.04	5.72	0.45
Aug 29	7.22	6.30	5.98	6.50	0.53
	GW-B 1	GW-B 2		MEAN	STD
July 18	10.37	10.08		10.23	0.14
July 25	11.48	11.48		11.48	
Aug 8	11.78	7.34		9.56	2.22
Aug 15	1.19	1.68		1.44	0.24
Aug 21	12.48	12.11		12.30	0.18
Aug 29	12.33	12.71		12.52	0.19
	STREAM 1	STREAM 2	STREAM 3	MEAN	STD
July 18	4.00	3.90	4.08	3.99	0.07
July 25	1.63	4.58	4.62	3.61	1.40
Aug 8	2.50	2.17	2.70	2.46	0.22
Aug 15	2.19	1.82	3.00	2.34	0.49
Aug 21	3.89	3.77	3.73	3.80	0.07
Aug 29	3.50	3.53	3.42	3.48	0.05
	TC 1	TC 2	TC 3	MEAN	STD
July 18	1.86	1.81	1.75	1.81	0.04
July 25	1.06	1.01	0.95	1.01	0.04
Aug 8	1.34	1.97	1.42	1.58	0.28
Aug 15	0.67	1.11	0.93	0.90	0.18
Aug 21	1.21	1.18	1.19	1.19	0.01
Aug 29	1.74	1.89	1.58	1.74	0.13

Table 19: pH and salinity measurements for the spring 1990 hydroperiod

pH

Date	**Location**			
	GW-A	**GW-B**	**STREAM**	**TC**
March 26				
April 2				
April 9	4.59	4.92	5.66	6.33
April 18	5.86	5.81	5.66	6.51
April 27	5.82	5.74	6.21	6.50
May 9	5.82	5.79	6.10	6.25
June 4				

Salinity (ppt)

Date	**Location**			
	GW-A	**GW-B**	**STREAM**	**TC**
March 26				
April 2	0.00	0.00	0.50	3.00
April 9	0.00	0.00	0.00	2.00
April 18	0.00	0.00	0.00	1.00
April 27	0.00	0.00	0.00	2.50
May 9	0.00	0.00	0.00	9.50
June 4	0.00	0.00	0.00	5.00

Table 20: pH and salinity measurements for the summer 1990 hydroperiod

pH

Date	Location			
	GW-A	GW-B	STREAM	TC
July 18	5.34	5.68	6.08	6.13
July 25	5.46	5.62	5.97	6.18
Aug 8	5.78	5.82	6.22	6.40
Aug 15	5.72	5.76	6.20	6.32
Aug 21	5.87	5.97	6.30	6.86
Aug 29	5.82	5.86	6.25	6.41

Salinity (ppt)

Date	Location			
	GW-A	GW-B	STREAM	TC
July 18	1.00	1.00	1.00	2.00
July 25	2.00	2.00	3.00	9.00
Aug 8	0.00	0.00	1.00	8.00
Aug 15	2.00	3.00	2.00	12.00
Aug 21	2.00	2.00	1.00	14.00
Aug 29	2.00	2.00	1.00	5.00

Table 21: Groundwater well water levels in cm for the spring and summer 1990 hydroperiods

Date	GW-A	GW-B
March 26	0.00	0.00
April 2	33.50	46.00
April 9	34.00	47.00
April 18	33.50	47.00
April 27	34.00	47.00
May 9	34.00	48.00
June 4	34.00	47.00
July 18	38.00	55.00
July 25	41.00	53.00
August 8	37.00	43.00
August 15	37.00	52.00
August 21	37.00	52.00
August 29	37.00	52.00

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