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Effect of a Water Treatment BMP on Nutrient Spiraling and Leaf Litter Breakdown in an Urban Stream

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EFFECT OF A WATER TREATMENT BMP ON NUTRIENT SPIRALING AND LEAF LITTER BREAKDOWN IN AN URBAN STREAM

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Effect of a Water Treatment BMP on Nutrient Spiraling and Leaf Litter Breakdown in an Urban Stream.

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by

Megan LeClair Wheeler

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We approve the thesis of Megan LeClair Wheeler as presented here.

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ABSTRACT

Alterations to stream conditions caused by urbanization can compromise valuable ecosystem services, such as nutrient attenuation and carbon processing. A best management practice (BMP) water facility was installed to restore an impaired urban stream in Columbus, GA. This study was conducted to determine the effect of this BMP on nutrient spiraling and leaf litter decomposition in a 2 km stretch of Weracoba Creek. I hypothesized the BMP would (1) reduce leaf mass loss over time and (2) interfere with nutrient concentrations and uptake lengths. I characterized leaf litter decomposition using tulip tree leaves (*Liriodendron tulipifera*) in 1mm mesh bags deployed upstream (1 site) and downstream (3 sites) of the BMP for 10 weeks (sampled bi-monthly, 3 replicates per site). I analyzed nitrate, phosphate, and nitrite concentrations bi-monthly (02/15/07-01/10/08) from three sub-surface grab samples taken at each of the four sites used in the leaf litter decomposition study. Leaf mass significantly declined over time, and was consistent across all four sites. Nitrate and nitrite concentrations remained consistent between pre- and post-construction, but phosphate increased during those periods. Nitrite showed consistently higher concentrations in the two upstream sites compared to the two downstream sites. Nitrate, phosphate, and nitrite uptake lengths remained unchanged pre- and post-implementation of the BMP. These results strongly suggest that the BMP had no positive effect on the two ecosystem services studied. Despite its impaired status, Weracoba Creek continues to provide some measure of services through leaf litter decomposition and nutrient retention.

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INTRODUCTION

Urbanization is increasing rapidly due to the growth of the world's population and the movement of people from rural areas to cities. Recent estimates place more than 50% of the human population in urban environments (Grimm et al. 2008). Streams draining urbanized basins experience a suite of stressors that degrade their ecological integrity, resulting in what Walsh et al. (2005) referred to as the urban stream syndrome. Urban streams are characterized by altered stream channel morphology, increased impervious surface within the basin, altered hydrographs, and increased concentrations of nutrients and other pollutants (Paul & Meyer 2001, Meyer et al. 2005, Walsh et al. 2005). Hatt et al. (2004) recognized urbanization as having negative effects on aquatic ecosystems due to reduced groundwater levels, increased flood flows, increased loads of pollutants, and greater erosion within the stream banks. These changes reduce fish and invertebrate biodiversity and impair bio-physical processes (Walsh et al. 2005). Urban development is ranked second only to agriculture as a threat to stream ecosystems, because over 130,000 km of rivers and streams in the U. S. alone are affected by urbanization (Paul & Meyer 2001, Malmqvist & Rundle 2002).

Urban development alters streams in a number of ways, particularly their hydrology (Miller & Boulton 2005). Impervious surfaces such as roofs, paved roads, and parking lots collect precipitation, which is then transported by storm drains to streams. This direct linkage between the basin and the stream results in flood events characterized by rapidly ascending and descending limbs of the hydrograph (Schoonover et al. 2006, Walsh et al. 2005). The percentage of impervious surface cover (ISC) of a land catchment is thought to be an accurate predictor of urban impacts on streams (McMahon

& Cuffney 2000). Paul & Meyer (2001) found that streams within a basin having an ISC of 10-20% experienced twofold greater runoff than forested catchments. Streams having catchments with high levels of impervious surface experience short duration, higher magnitude flows and shorter return intervals (Schoonover et al. 2006, Walsh et al. 2005). Impervious surfaces allow pollutants such as polycyclic aromatic hydrocarbons, mineral oil hydrocarbons, and heavy metals such as cadmium, copper, zinc, and lead to collect until a rain event, when they are washed into storm sewers and are flushed directly out into surrounding streams, creeks, and rivers (Göbel et al. 2007).

Rivers, even those in urbanized basins, provide natural resources and ecosystem services that have value to humans. These services are often underappreciated, because economists have found it difficult to estimate their value. Costanza et al. (1987) estimated the annual value of ecosystem services by all natural areas, including rivers, as US $33 trillion. Rivers provide services such as water regulation, water supply, recreation, waste treatment, nutrient cycling, and food supply. The total value of ecosystem service that is provided by rivers/lakes is about US $17 trillion per year (Costanza et al. 1987). Alterations to stream conditions caused by urbanization can lead to the loss of these valuable ecosystem services. It is important to study nutrient concentrations in streams because changes in concentration and/or composition can affect the functions of a stream community (Meyer et al. 1988). Nutrient levels within a stream are important because they influence the rate at which many ecosystem services occur. For example, the amount of nutrients present in a stream can affect the rates at which leaf matter is broken down (Spänhoff et al. 2007). Thus, leaf litter breakdown rates can be used to measure ecosystem response to disturbance and can be used to compare several stream ecosystems (Paul et al. 2006).

Leaf litter breakdown

Leaf litter breakdown is an important ecosystem process that is regulated by both biological and physical factors (Pascoal et al. 2005). Leaf litter provides energy and shelter resources for microbes and macroinvertebrates and their consumers (Meyer et al. 2005). Leaves enter the stream ecosystem and within one or two days, begin to leach soluble nutrients into the water, initiating the release of dissolved organic matter (DOM) (Benfield 2006). Decomposition of leaf litter begins when aquatic fungi, algae, and bacteria colonize the leaves (Baldy et al. 2007). The result of this decomposition is coarse particulate organic matter (CPOM). Bacteria, aquatic hyphomycetes, macroinvertebrates, and physical processes in the stream reduce the CPOM into fine particulate organic matter (FPOM) which is then further reduced to DOM (Baldy et al. 2007). The macroinvertebrate shredders (e.g., *Lepidostoma*, *Allocapnia*, *Taeniopteryx*, *Peltoperla*, and *Pycnopsyche*) reduce leaf material into FPOM, providing energy for filtering and gathering macroinvertebrate collectors downstream (Paul et al. 2006). These organisms are sensitive to environmental stress factors such as high concentrations of nitrate, phosphorus, sulphate, heavy metals, and low concentrations of dissolved oxygen (Solé et al. 2008). Elevated concentrations of nitrogen and/or phosphorus can cause eutrophication and result in the loss of many organisms, including sensitive shredder taxa (Pascoal et al. 2005). Rates of litter breakdown are associated with the health of a stream because fungi, bacteria, and invertebrates are instrumental in leaf litter decomposition (Paul et al. 2006).

The effect of urbanization on leaf decomposition is difficult to predict. Urban streams are often marked by their lack of species richness, usually having more pollution tolerant invertebrates (e.g., chironomids and oligochaetes) present than in non-urban streams (Paul & Meyer 2001). In some streams, decomposition rates are lowered due to a decreased abundance of shredders (Pascoal et al. 2005). This decrease can lead to alterations in insect biodiversity and other ecosystem services by removing important constituents in the leaf decomposition cycle or nutrient cycle (Paul et al. 2006). Leaf litter breakdown is also affected by nutrient spiraling, so it is important to study both of these processes.

Nutrient spiraling

Nutrients play an important role in stream food webs, (Gibson & Meyer 2007) regulating primary productivity and decomposition; therefore changing the concentration of the nutrients can alter stream community structure (Meyer et al. 1988). Francoeur's (2001) meta-analysis found that more than 50% of studies show a nitrogen, phosphorus, or co-limitation of the stream periphyton. Stream periphyton is composed of tiny organisms such as protozoans, insect larvae, bacteria, and algae that live on solid surfaces. Gulis et al. (2004) found increased microbial activity and fungal biomass in a three year, whole-stream nutrient enrichment study.

Nutrients can regulate many processes within a stream, but they are also regulated by several factors such as precipitation or adsorption to particles in the water column or sediments, microbial uptake, and hydrologic influences (Allan and Castillo 2007). The transformation of nutrients as they are carried downstream has been referred to as nutrient spiraling (Allan and Castillo 2007). One way to characterize nutrient spiraling is to determine nutrient uptake lengths. These lengths describe the average distance that nutrient atoms are transported before being altered by either abiotic or biotic processes (Gibson & Meyer 2007). In this study uptake lengths were used as an indicator of ecosystem services. When uptake lengths are short, rates of nutrient transformation and attenuation are elevated.

Many studies have documented the negative effects of urbanization on ecosystem services, however, less is known about the effectiveness of techniques to restore ecosystem functions in these degraded systems. The number of stream restoration projects has increased during the last 30 years (Bernhardt et al. 2005). Unfortunately, many of these restoration projects have been implemented without specific, measurable goals and were not evaluated for their effectiveness (Bernhardt et al. 2007, Kondolf et al. 2007). Designers of these projects focused on stream aesthetics or channel morphology rather than restoring ecosystem services (Miller & Boulton 2005).

This study was designed to characterize the effectiveness of an innovative water treatment best management practice (BMP) (Fig. 1) to restore an impaired, urban stream in Columbus, GA. The BMP was designed to kill fecal coliform bacteria using ultraviolet radiation (UVR), filter coarse particulate organic matter, and reduce peak storm flows. This design may have unintended affects on ecosystem services such as leaf degradation and nutrient spiraling. Using a pre- and post-implementation study of the upstream and downstream effects of this BMP, I characterized leaf litter mass loss and nutrient concentration changes over a one year period. I hypothesized the BMP would (1) reduce leaf mass loss over time and (2) interfere with nutrient concentrations and uptake lengths.

METHODS

Study sites

Weracoba Creek, is a third order creek that drains the central portion of Columbus, Georgia (Muscogee County). The creek's length is approximately 11.3 km and the channel has been straightened and revetted. The watershed lies in the West Georgia Piedmont and is classified as an urban area within the Middle Chattahoochee Watershed (Schoonover et al. 2006). Schoonover and Lockaby (2006) reported Weracoba Creek's watershed (Fig. 2) as having 49.5% impervious surface, 32.4% canopy, and 12.9% grazing. This creek is designated as a non-attainment water body for fecal coliforms on Georgia's 303(d) list (GAEPD 2008).

The BMP examined in this study was designed to treat Weracoba creek in several ways (Fig. 1). During baseflow conditions (dry flow) the stream is treated with UVR to kill fecal coliform bacteria. In wet weather conditions the first flush of water is diverted to treatment (stage 1) and a compressed media filter is used to remove solid influent wastes. Excess wet weather flow is allowed to bypass treatment (stage 2) but the upstream head is maintained for flood control purposes. Peak by-pass flow (400 cfs) maintains the head on water treatment BMP (stage 3). At peak flow (1600 cfs) water moves through and over the flow control structure before downstream bridge restriction submerges the BMP facility (stage 4).

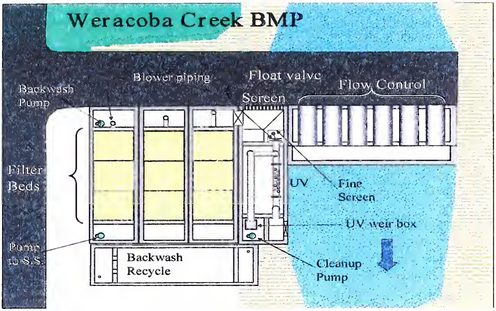

Figure 1. Diagram of the Weracoba Creek BMP facility and its aspects of treament. Image courtesy of Columbus Water Works

The study began February 15, 2007 and continued through January 10, 2008. I evaluated the effects of the water treatment facility at four different sites along the creek. These four sites are located within a 2 km stretch of the creek starting at the north end of Lakebottom Park and ending at Warren Williams Road where the creek flows below ground into a culvert. The control site (Fig. 2, site 1) was located 150 m upstream from the facility and the three experimental sites were located 230 m, 1050 m, and 1900 m downstream from the control site (Fig 2., sites 2, 3, and 4 respectively).

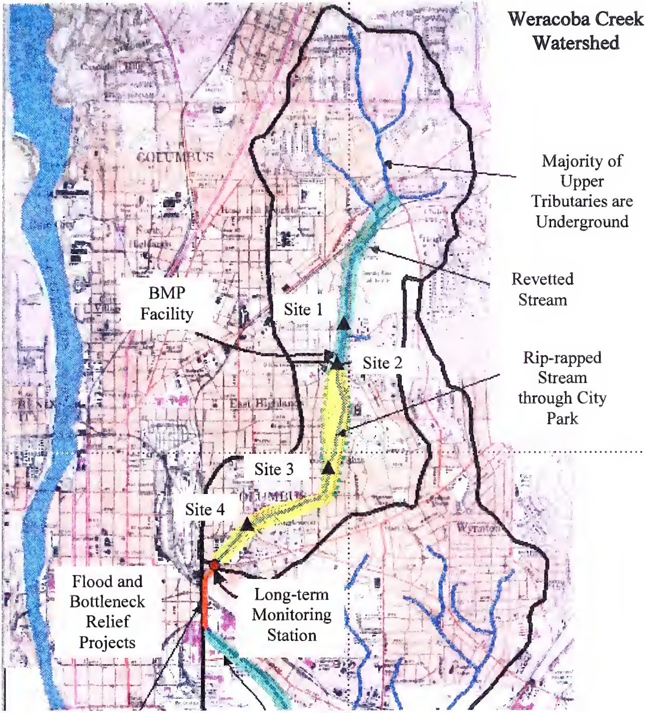

Figure 2. Weracoba Creek Watershed. Lake Bottom Park is outlined and labeled as a rip-rapped stream through city park; study sites are labeled and marked by the triangles. Image courtesy of Columbus Water Works.

Leaf litter breakdown

Leaf litter breakdown was used in this study to analyze whether the water treatment facility altered the amount of in-stream CPOM processed. Tulip tree leaves (*Liriodendron tulipifera*) were collected from the trees by hand just before abscission and immediately transported in coolers to the lab. This species of leaves was used for this study because the trees were located within the study area and the leaves have a half-life of about 65 days. The breakdown rate of the leaves can be observed within a short period of time but is not so rapid that the leaves would be completely decomposed within the first week of the experiment. To reduce variation in initial leaf size and shape variability, I cut leaves into 30 mm diameter disks. The leaf circles were dried in an oven for a minimum of 24 h at 105°C, and then the dry mass of each leaf circle was measured using an analytical top-loading balance. Two leaf circles were placed in 5 x 10 cm bags constructed from 1 mm mesh, and closed with monofilament line. Just before deploying the leaf packs, I attached three mesh bags to a single brick using monofilament line or nylon string. At each of the four study sites, I placed eight bricks on the stream bed and measured the flow (m/s) and depth (cm) for each (Table 1). Seven of the bricks at each site had three packs per brick, with the eighth brick only having one leaf pack attached. The bricks were placed on the bottom of the stream bed, avoiding areas of high flow velocity or uneven substrate, where they might be washed downstream.

Table 1. Average (± 1 S.E.) depth (cm) and flow (m/s) measurements for brick locations at each site within Weracoba Creek.

Site	Depth (cm)	Flow (m/s)
1	23.4 ± 0.5	0.01 ± 0.006
2	28.2 ± 1.3	0 ± 0
3	27.6 ± 1.4	0 ± 0
4	22.2 ± 1.1	0.01 ± 0.005

The leaf pack study was initiated on October 18, 2007 and continued until December 13, 2007. At approximately two week intervals, I collected one brick from each site, removed the leaf packs, and transported them on ice to the lab in plastic bags. At the lab, the contents of each mesh leaf pack were rinsed with tap water to remove sand, invertebrates, and other materials that collected in the bags. All leaf material was dried to constant mass for 24 h at 105°C and weighed to the nearest 0.1mg using an Ohaus® Adventurer SL AS214 top-loading balance. Because the leaves had begun to disintegrate during the study, I summed the total mass for both leaf disks to get an estimate of mass for each leaf pack.

Nutrients

To assess the effect of the treatment facility on nutrient dynamics in Weracoba Creek, I collected subsurface water grab samples at each site every two weeks beginning on February 15, 2007 and continuing through January 10, 2008. Nalgene® bottles (500 mL) were rinsed with creek water and then used to collect three independent samples at haphazardly selected points within each site, during each visit. I transported samples on ice to the lab for analysis. Nitrate ($N\text{-}NO_3^-$, mg/L) concentrations were then measured in each sample by following Hach method 8039, a cadmium reduction method.

Phosphate ($P\text{-}PO_4^{3-}$, mg/L) concentrations were analyzed following US EPA method 365.2 and Standard Method 4500-P-E for each sample. Nitrite ($N\text{-}NO_2^-$, mg/L) concentrations were measured using the method from the Federal Register, 44(85) 25505 (May 1, 1979) for each sample. All samples were analyzed within 48 hours using a Hach® DR/2010 spectrophotometer.

To determine the impact of the BMP on changes in nutrient concentrations, uptake lengths were calculated for nitrate, phosphate, and nitrite for each bi-monthly sample. I calculated uptake length as the difference in concentration between site 1 and site 4 divided by 1.9 km (distance between sites). I selected site 1 and site 4 because these sites showed the greatest difference in concentration during the period of the study. I averaged the nutrient concentrations for the three replicates for each site before performing uptake length calculations.

Physical measurements

Several measurements of the physical characteristics of the study sites were also taken during the study. During each bi-monthly visit, I measured temperature (°C), dissolved oxygen (mg/L), and pH at three randomly selected locations (per site) using a Hydrolab® Multi-probe Surveyor 3, according to manufacturer recommendations (Hydrolab 1995), moving from downstream to upstream to minimize substrate disturbance. I calibrated the Hydrolab Surveyor 3 for pH and dissolved oxygen in the lab before taking any in-stream measurements on each sample date.

Additional physical measurements were taken on 05/22/08. Canopy cover was measured at each site by the proportion of squares more than half covered by vegetation in the hemispherical, convex densiometer. I averaged the proportions for observations taken facing all four cardinal directions (Keller et al. 2005). The width of the stream was measured from water edge to water edge. Depth was reported as the average of five, equally spaced measurements across the stream. GPS coordinates were taken using a WAAS enabled, handheld Garmin™ GPSmap76CSx.

Statistical analysis

I used two approaches to analyze site differences in physical characteristics. Temperature, dissolved oxygen (DO), and pH were analyzed together using a multiple analysis of variance (MANOVA). Because MANOVAs incorporate multiple dependent variables simultaneously, I used multiple, univariate ANOVAs for each dependent variable (temperature, DO, and pH). Site differences in flow and depth were analyzed using univariate ANOVAs with site as the independent variable ($n=5$ per site). Tukey HSD tests were used for all post hoc pairwise comparisons, because they correct for the number of comparisons.

Differences in dry leaf mass among the four sites were assessed using a two-way analysis of variance (ANOVA) with date and site as independent variables. There were six sample dates included in the analysis (Initial and 10/18/07-12/13/07). Tukey HSD tests were used for all post hoc pairwise comparisons. The initial mass of the leaf packs at each site was also tested using a one-way ANOVA to determine if there was a significant difference in the amount of leaf mass placed at each site at the beginning of the study.

The sampling period was divided into three groups: pre-construction, construction, and post-construction. Because pre-construction, construction, and post-construction periods were not equal in length I used stratified random sampling to designate four sample dates per group. The dates of each group are as follows: Pre-construction was 2/15/07-4/30/07, Construction was from 5/01/07-10/31/07 and Post-construction was from 11/1/07-12/13/07. A MANOVA was used to analyze the effect of the BMP on nitrate, phosphate, and nitrite concentrations with site and group as independent variables. Because MANOVAs incorporate multiple dependent variables simultaneously, I used univariate ANOVAs to subsequently determine which dependent variables were most affected by the two independent variables. Tukey HSD tests were carried out for all post hoc pairwise comparisons.

In order to determine the effect of the BMP on nutrient dynamics, I compared pre- and post-BMP implementation uptake lengths using an independent samples *t*-test. To maximize the sample size and statistical power, I defined the pre-BMP period as the six sample dates prior to the start of construction (2/15/07- 4/26/07) and the post-BMP period as the six sample dates after the BMP went on-line (11/1/07-1/10/08). A Pearson correlation was used to determine the strength of the association between nitrite and phosphate uptake lengths for all sampling dates (n=24).

All statistical analyses were performed using SPSS for Windows v15.0 software. Differences for all analysis were considered statistically significant when p values were less than 0.05.

RESULTS

Study sites

The 2 km stretch of Weracoba Creek that I studied is shallow (<30 cm), narrow (<6 m), warm (~21°C), and slow (<0.12 m/s) with a neutral pH (~6.9). Stream depth (ANOVA, $F_{3,16}=3.429$, $p=0.043$) and dissolved oxygen (ANOVA, $F_{3,84}=5.191$, $p<0.002$) differed significantly among the sites (Table 2). Dissolved oxygen concentrations were significantly greater at site 4 (where I often observed filamentous algae/cyanobacteria) than at site 2 (Tukey HSD, $p=0.001$). Canopy density was four times lower at site 4 than at the other three sites.

Table 2. Mean (± 1 S.E.) physical, hydrological, chemical, and biological characteristics of Weracoba Creek at the four study sites. Values not sharing a letter are statistically significant (p<0.05) using Tukey HSD post hoc pairwise comparisons.

	Site 1	Site 2	Site 3	Site 4
GPS location	32°29'04.54"N 84°57'53.20"W	32°28'58.55"N 84°57'54.50"W	32°28'32.91"N 84°57'55.93"W	32°28'14.56"N 84°58'14.50"W
Channel width (cm)[1]	357	517	577	420
Depth (cm)[2]	13.52 ± 3.3 [a]	28.96 ± 3.9 [b]	24.5 ± 3.5 [a,b]	16.52 ± 4.5 [a,b]
Flow (m/s)[2]	0.12 ± 0.065	0 ± 0.002	0.01 ± 0.002	0.02 ± 0.01
Canopy Density (%)[1]	71	54	65	13
Temperature (°C)[3]	21.1 ± 1.1	21.4 ± 1.1	21.0 ± 1.2	21.4 ± 1.3
Dissolved oxygen (mg/l)[3]	7.2 ± 0.3 [a,b]	6.5 ± 0.3 [a]	7.2 ± 0.4 [a,b]	8.4 ± 0.4 [b]
pH[3]	6.8	6.9	6.9	7.0

[1] Measured on 5/22/08 and was not analyzed statistically
[2] Measured 5/22/08 (n=20)
[3] Measured 2/15/07-12/13/07 (n=264)

Temperature varied approximately 20 degrees over the course of the study, with the maximum temperature recorded in August and the minimum in February (Fig. 3). Temperature variation between sample dates (~2 weeks) was slight with a maximum difference of approximately 5 °C.

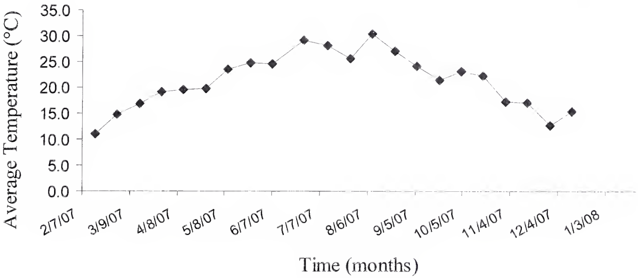

Figure 3. Average values of temperature measured bi-monthly in Weracoba Creek, from 2/15/07 to 12/13/07. Average value calculated from all four sites for each sample date.

Leaf litter breakdown

In order to determine if the leaf packs had similar initial masses, I analyzed the average mass of leaves for all bricks used in the study. Initial leaf mass did not significantly differ among sites. Leaf mass decreased significantly over time (Fig. 4, two-way ANOVA, $F_{5,48}=28.8$, $p<0.0005$). The samples collected between 11/15/07 to 12/13/07 had significantly less mass than the sample collected on 11/01/07 (Tukey HSD, $p<0.005$). Although leaf mass decreased significantly over time, there were no significant differences in leaf mass among sites on any given sample date.

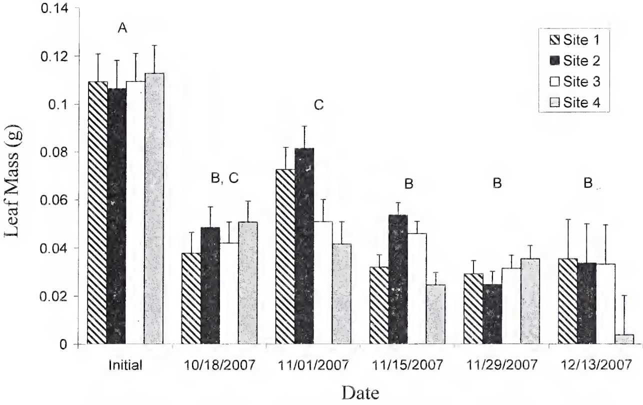

Figure 4. Mean (±1 S.E.) dry mass of *Liriodendron tulipifera* leaves placed at four sites in Weracoba Creek, GA and collected over 10 weeks. Site 1 is upstream of the BMP and sites 2-4 are located progressively downstream Dates not sharing a letter are statistically significant ($p<0.05$) using Tukey HSD post hoc pairwise comparisons. Bars labeled Initial indicate the dry mass of leaves on a brick, randomly selected prior to deployment in the creek.

Nutrients

To examine whether the water treatment facility altered nutrient dynamics, I compared nitrate, nitrite, and phosphorus concentrations among sites and groups (Fig. 5). Considering all nutrient species together I found significant differences in nutrient concentrations among sites (MANOVA Wilkes, $\lambda=0.726$, $p<0.0005$) and groups (MANOVA Wilkes, $\lambda=0.576$, $p<0.0005$) but there was no significant interaction between these two variables. However, individual nutrients differed in their response among sites and groups (Fig. 5).

Nitrate concentrations (Fig. 5a) were similar upstream and downstream of the facility throughout the study period when average values ranged from 0.5 to 0.9 mg/L. Phosphate concentrations significantly differed among groups (Fig. 5b, two-way ANOVA, $F_{2,132}$=23.988, $p<0.001$). Average post-construction concentrations (~0.16 mg/L) were at least four times greater than during pre-construction (Fig. 5b, Tukey HSD, $p< 0.0005$). Phosphate concentrations during construction were significantly greater than pre-construction (Tukey HSD, $p=0.027$) and significantly less than post-construction (Tukey HSD, $p<0.0005$). Phosphate concentrations did not differ among sites. Nitrite concentrations differed significantly among study sites (Fig. 5c, ANOVA, $F_{2,132}$=12.706, $p<0.001$) and groups (ANOVA, $F_{2,132}$=7.760, $p=0.001$). Sites 1 and 2 had higher nitrite concentrations than sites 3 and 4 during pre-construction, construction, and post-construction (Fig 5c, Tukey HSD, $p<0.05$ for all). Nitrite concentrations were higher pre- and post-construction (Fig 5c, Tukey HSD, $p<0.003$ for both) compared to the construction period.

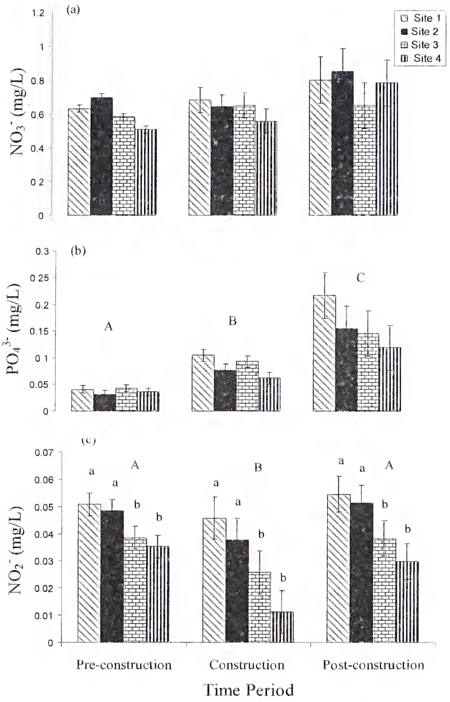

Figure 5. Mean (±1 S.E.) nitrate (a), phosphate (b), and nitrite (c) concentrations in Weracoba Creek before, during, and after the installation of the water treatment facility. The different lowercase letters designate significant differences ($p<0.05$) between sites, and the different capital letters designate significant differences ($p<0.05$) between the time periods.

Uptake lengths

There were no significant differences in the uptake lengths of nitrate, phosphate, and nitrite (*t*-test, t>0.48, df=10, p>0.093 for all) between pre-and post-BMP implementation periods (Fig. 6). Nitrate, phosphate, and nitrite uptake lengths were all highly variable (coefficient of variation > 146% for all) and at times were negative, possibly indicating unmonitored nutrient inputs along the stream. Phosphate and nitrite showed at least two distinctive spikes in uptake lengths, however over the period of record there was not a significant correlation between their uptake lengths (Pearson correlation=0.391, p=0.059).

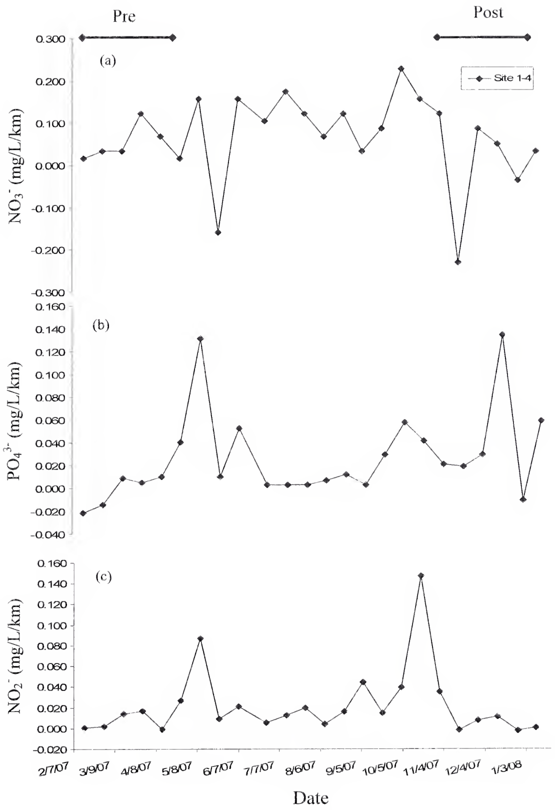

Figure 6. Average nitrate (a), phosphate (b), and nitrite (c) uptake lengths in Weracoba Creek from 02/15/07-01/10/08. Horizontal lines indicate the groups, pre- and post-BMP implementation used in statistical analyses.

DISCUSSION

Leaf litter breakdown

The overall mass of leaf litter declined after deployment in the creek, and the decline was most significant after the initial two weeks in the stream. Standard models of leaf litter decay predict greater mass losses (up to 25% initial dry mass within first 24 h) in the initial stage of leaf litter decomposition occurring over a short period due to leaching of dissolved organic matter (DOM) (Webster and Benfield 1986). In this experiment, leaves remained in the creek for up to 10 weeks, however little change in mass occurred during the last 6 weeks. I did not find any differences in leaf mass remaining among sites for any of the sample dates, thus my hypothesis was not supported. I hypothesized higher leaf mass at sites 2, 3, and 4 because the BMP was thought to impair microbial activity which would result in reductions of leaf litter decomposition rates. The BMP was designed to sterilize water containing elevated levels of fecal coliform bacteria using UVR because even ambient levels of solar radiation have been shown to decrease bacterial cell densities and accrual rates (Hodoki 2005). The UVR treatment is not species specific and may be negatively effecting other microbes involved in the leaf degradation process.

Abiotic factors such as stream bed channelization, high flow velocity, and storm runoff can also affect the rate of mechanical breakdown of leaves (Paul et al. 2006). All four sites may have been influenced by these factors, masking any effects caused by the treatment facility. Spänhoff et al. (2007) found the breakdown rate of leaf litter to be significantly higher at the effluent site of a wastewater treatment plant than at a control site and speculated that it was due to higher temperatures and increased flow velocity. Paul et al. (2006) proposed that nutrient enrichment would lead to elevated leaf decay rates in agricultural streams while rates in urban streams are enhanced by increased flow velocity during storm events. Paul et al. (2006) reported concentrations of total phosphorus (0.034 mg/L) and nitrogen (0.62 mg/L) in Atlanta urban streams. Weracoba Creek phosphate concentrations, which are a fraction of total phosphorus, ranged from 2-3 times higher than those reported in Paul et al. (2006). The elevated levels of phosphorus in this stream may have influenced the rate of leaf decomposition in a manner similar to that of the agricultural streams (Paul et al. 2006).

Other studies such as Meyer et al. (1988) confirm that nutrient concentrations can influence decomposition rates. However, nutrient enrichment does not always have positive effects on leaf decomposition rates. Nutrient availability within the water column, mainly N and P, was found to slow fungal activity, decreasing decomposition rates of leaves in a study by Gonçalves et al. (2007). I did not measure ammonia in this study, but urban streams often have increased concentrations of this nutrient. Baldy et al. (2007) found the shredder biomass decreased dramatically as ammonia concentration gradually increased, affecting leaf litter decomposition budgets.

Nutrients

Nutrient concentration patterns were unaffected by implementation of the water treatment BMP. If the BMP was affecting nutrient concentrations, I would have expected to observe different patterns before and after the device was installed. The only nutrient that showed decreased concentrations downstream was nitrite and that pattern remained constant among pre- and post-BMP implementation. Furthermore, phosphate actually increased after the implementation of the BMP. Nitrate was relatively constant throughout the study. These lines of evidence suggest that the BMP did not improve nutrient attenuation in the stream.

Tank et al. (2000) found that nutrient uptake is a function of the distance between sites. In my study, these differences were only measurable for nitrite between sites 2 and 3 which are 820 m apart. Since nitrite is converted to nitrate in the presence of oxygen downstream transport may cause concentration reductions. Surprisingly, sites 3 and 4 are 850 m apart but no detectable differences in nitrite concentrations were found. The presence of storm drain pipes could have influenced nutrient concentrations within the stream. Weracoba Creek also fowes underground for about 100 meters. The lack of sunlight could have affected algal and microbial growth, which in turn could have affected nutrient uptake. However none of the nutrients measured showed increasing concentrations at the downstream sites.

Phosphate concentrations began increasing during the construction phase of the BMP. Fisher et al. (1998) found an increase in the processing lengths of nutrients due to disturbances within the stream bed. The construction process disturbed sediments within the stream bed and may have caused re-suspension of nutrients into the water column, elevating concentrations (Gibson & Meyer 2007).

Uptake lengths

Grimm et al. (2008) found that retention rates of nitrogen and phosphorus are lower in urban streams because the cycles in which the nutrients are processed are often disrupted. I found that nutrient retention was generally positive for nitrate, phosphate, and nitrite for most of the sample dates in Weracoba Creek. However uptakes lengths were highly variable through time for all nutrients. In contrast, Gibson & Meyer (2007) found that nitrogen uptake lengths in the Chattahoochee River were much more variable than phosphate uptake lengths. Simon et al. (2005) found spring and summer months to have shorter uptake lengths than the fall and winter months. However, my results do not show strong seasonal trends in nutrient uptake lengths.

If my hypothesis regarding nutrient concentrations had been supported then I would have expected shorter nutrient uptake lengths during the post-BMP implementation period. However these differences were not observed. If the BMP is having positive or negative impacts on ecosystem services such as nutrient spiraling, the creek may need time to respond fully to the changes. The response time of biota to these changes may range from weeks for microbes, months for macroinvertebrates, and years for vertebrates (Minshall 1988). My study ended shortly after the water treatment BMP went online due to changes in the construction schedule and launch date of the BMP so long term effects were not observed.

Conclusions

Urbanization of watersheds often results in degraded streams that have compromised ecosystem processes. These streams may still provide valuable ecosystem services such as water conveyance and pollutant transport even if they are biologically impoverished. While restoring streams in urban areas is important, the impacts and effectiveness of restoration actions must be carefully monitored before and after implementation. Since many restoration projects seek to solve a perceived problem such as bacterialization or channelization, little effort has been directed to creating projects to re-establish functioning ecosystem services.

For streams affected by urbanization, the enhancement of ecosystem services may provide the most reasonable, quantifiable goals for restoration projects. In the case of this restoration projects, the focus was to improve Weracoba Creek water quality and remove it from Georgia's 303d list of impaired waters. Specifically, the BMP was designed to sterilize the stream water to remove fecal coliform bacteria. The BMP's auxiliary filters and check dam were also constructed to reduce downstream debris and sediment transport. Columbus Water Works, Inc. and its partners have monitored fish and invertebrate communities prior to and after installation of the BMP, but little consideration has been given to the BMP's effects on other important ecosystem services. My results suggest that the BMP has had few positive or negative short-term impacts on leaf litter breakdown rates and nutrient retention in Weracoba Creek. Noticeable increases in nitrogen and phosphorus concentrations did occur during various phases of the construction process but had few lasting effects. What remains unknown is whether these services within Weracoba Creek will show either positive or negative long term responses to the BMP. The future of these new restoration designs such as that used in

Weracoba Creek need to establish quantifiable goals that consider the full suite of ecosystem services that urban streams are capable of providing.

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APPENDIX A

WERACOBA CREEK PHYSICAL AND CHEMICAL MEASUREMENTS

Date	Site #	Temp (C)	Dissolved Oxygen (mg/L)	pH	NO_3^- -N (mg/L)	Correction NO_3^- -N (mg/L) *	PO_4^{3-} -P (mg/L)	NO_2^- -N (mg/L)
2/15/2007	1	11.1	11.3	8.3	1.2	0.8	0.06	0.013
2/15/2007	1	11.1	11.4	8.1	1.1	0.7	0.06	0.021
2/15/2007	1	11.1	11.1	8	1.1	0.7	0.07	0.022
2/15/2007	2	11.8	11.4	8.4	1.1	0.7	0.03	0.018
2/15/2007	2	11.7	11.4	8.2	1.2	0.8	0.03	0.023
2/15/2007	2	11.8	11.3	8.1	1.1	0.7	0.02	0.048
2/15/2007	3	10.9	12.1	8.4	1.1	0.7	0.03	0.016
2/15/2007	3	10.9	11.9	8.1	1.1	0.7	0.03	0
2/15/2007	3	10.9	11.7	8.1	1	0.6	0.02	0.017
2/15/2007	4	10.5	12.5	8.4	1.1	0.7	0.11	0.018
2/15/2007	4	10.5	12.4	8.2	1.1	0.7	0.11	0.018
2/15/2007	4	10.5	12.3	8	1.1	0.7	0.09	0.018
3/1/2007	1	14.8	8.8	7.8	1.1	0.7	0.04	0.029
3/1/2007	1	14.8	8.6	7.7	1.1	0.7	0.02	0.03
3/1/2007	1	14.8	8.7	7.6	1.1	0.7	0.02	0.03
3/1/2007	2	15	8.3	7.4	1.2	0.8	0.02	0.027
3/1/2007	2	15	8.3	7.3	1.8	1.4	0.03	0.027
3/1/2007	2	15	8.3	7.2	1.4	1	0.01	0.026
3/1/2007	3	14.4	8.5	7.9	1.2	0.8	0.07	0.026

Continued Date	Site #	Temp (C)	Dissolved Oxygen (mg/L)	pH	NO_3^- -N (mg/L)	Correction NO_3^- -N (mg/L) *	PO_4^{3-} -P (mg/L)	NO_2^- -N (mg/L)
3/1/2007	3	14.4	8.5	7.8	1.1	0.7	0.09	0.026
3/1/2007	3	14.4	8.4	7.7	1	0.6	0.05	0.026
3/1/2007	4	14.6	9.6	7.9	1.1	0.7	0.06	0.023
3/1/2007	4	14.6	9.9	7.8	1	0.6	0.05	0.031
3/1/2007	4	14.6	9.9	7.7	1	0.6	0.05	0.022
3/15/2007	1	16.9	7.5	7.5	1	0.6	0.03	0.052
3/15/2007	1	16.9	7.5	7.3	1.1	0.7	0.03	0.054
3/15/2007	1	17	7.4	7.2	1.1	0.7	0.02	0.056
3/15/2007	2	17.1	6.9	7.3	1.1	0.7	0.02	0.046
3/15/2007	2	17.1	7	7.3	1	0.6	0.02	0.054
3/15/2007	2	17.1	7	7.2	1.1	0.7	0.01	0.045
3/15/2007	3	16.9	7.4	7.5	1	0.6	0.01	0.028
3/15/2007	3	16.9	7.5	7.4	1	0.6	0.01	0.041
3/15/2007	3	16.9	7.3	7.3	0.9	0.5	0.01	0.026
3/15/2007	4	17	7.5	7.7	1	0.6	0.01	0.029
3/15/2007	4	17	7.6	7.6	1	0.6	0.01	0.027
3/15/2007	4	16.9	7.6	7.5	1	0.6	0.01	0.026
3/29/2007	1	19.7	8.4	7.3	1	0.6	0.04	0.058
3/29/2007	1	19.7	8.4	7.2	1	0.6	0.04	0.06
3/29/2007	1	19.8	8.3	7.1	1.1	0.7	0.02	0.077
3/29/2007	2	19.1	8.1	7.6	0.9	0.5	0.03	0.069
3/29/2007	2	19.2	8.0	7.4	1	0.6	0.03	0.074
3/29/2007	2	19.2	8.0	7.4	1	0.6	0.01	0.076
3/29/2007	3	18.9	7.9	7.8	1	0.6	0.04	0.052
3/29/2007	3	18.9	7.7	7.6	1.1	0.7	0.04	0.054

Continued Date	Site #	Temp (C)	Dissolved Oxygen (mg/L)	pH	NO_3^- -N (mg/L)	Correction NO_3^- -N (mg/L) *	PO_4^{3-} -P (mg/L)	NO_2^- -N (mg/L)
3/29/2007	3	18.9	7.7	7.5	1.1	0.7	0.03	0.047
3/29/2007	4	18.9	8.7	7.9	0.8	0.4	0.02	0.033
3/29/2007	4	18.9	8.7	7.8	0.7	0.3	0.02	0.033
3/29/2007	4	18.9	8.8	7.7	0.9	0.5	0.03	0.032
4/12/2007	1	20.4	7.9	7.9	0.9	0.5	0.08	0.057
4/12/2007	1	20.0	7.8	7.5	0.9	0.5	0.08	0.053
4/12/2007	1	20.0	7.6	7.4	1.0	0.6	0.07	0.054
4/12/2007	2	20.7	8.3	7.3	0.9	0.5	0.07	0.050
4/12/2007	2	20.7	8.0	7.2	0.9	0.5	0.07	0.045
4/12/2007	2	20.7	8.0	7.1	0.9	0.5	0.06	0.043
4/12/2007	3	18.3	8.0	7.6	0.8	0.4	0.06	0.045
4/12/2007	3	18.3	8.1	7.5	0.8	0.4	0.06	0.046
4/12/2007	3	18.4	8.1	7.4	0.8	0.4	0.05	0.046
4/12/2007	4	19.3	8.8	7.9	0.8	0.4	0.06	0.055
4/12/2007	4	19.3	8.9	7.7	0.9	0.5	0.06	0.055
4/12/2007	4	19.3	8.8	7.5	0.7	0.3	0.05	0.057
4/26/2007	1	19.7	6.4	7.6	0.9	0.5	0.11	0.113
4/26/2007	1	19.7	6.2	7.2	0.9	0.5	0.11	0.115
4/26/2007	1	19.7	6.9	7.1	1.0	0.6	0.11	0.116
4/26/2007	2	19.8	6.1	7.4	0.9	0.5	0.09	0.108
4/26/2007	2	19.8	5.9	7.2	0.9	0.5	0.09	0.112
4/26/2007	2	19.8	6.0	7.1	0.9	0.5	0.09	0.111
4/26/2007	3	19.6	6.7	7.5	1.0	0.6	0.06	0.138
4/26/2007	3	19.6	6.5	7.4	1.0	0.6	0.07	0.140
4/26/2007	3	19.6	6.6	7.3	1.0	0.6	0.06	0.137

Continued Date	Site #	Temp (C)	Dissolved Oxygen (mg/L)	pH	NO_3^- -N (mg/L)	Correction NO_3^- -N (mg/L) *	PO_4^{3-} -P (mg/L)	NO_2^- -N (mg/L)
4/26/2007	4	20.0	7.5	7.9	0.9	0.5	0.04	0.066
4/26/2007	4	20.0	7.4	7.7	0.9	0.5	0.02	0.060
4/26/2007	4	20.0	7.5	7.6	0.9	0.5	0.04	0.065
5/10/2007	1	24.4	7.8	7.1	1.3	0.9	0.35	0.270
5/10/2007	1	24.1	6.9	7.1	1.4	1.0	0.29	0.266
5/10/2007	1	24.2	7.7	6.9	1.2	0.8	0.30	0.266
5/10/2007	2	24.0	6.7	7.1	2.0	1.6	0.28	0.220
5/10/2007	2	24.2	6.9	7.0	2.0	1.6	0.25	0.214
5/10/2007	2	24.2	6.9	7.0	1.9	1.5	0.26	0.218
5/10/2007	3	21.8	8.3	7.5	1.1	0.7	0.07	0.155
5/10/2007	3	21.9	8.5	7.4	1.0	0.6	0.07	0.156
5/10/2007	3	22.0	8.5	7.4	1.0	0.6	0.07	0.157
5/10/2007	4	23.7	12.5	9.0	1.0	0.6	0.07	0.097
5/10/2007	4	23.8	12.6	9.0	0.9	0.5	0.06	0.106
5/10/2007	4	23.8	10.1	9.0	1.1	0.7	0.06	0.105
5/24/2007	1	23.3	8.3	8.3	1.2	0.8	0.09	0.034
5/24/2007	1	23.3	8.2	8.1	1.7	1.3	0.06	0.030
5/24/2007	1	23.3	7.4	8.1	1.1	0.7	0.04	0.032
5/24/2007	2	24.3	7.4	8.6	1.3	0.9	0.05	0.037
5/24/2007	2	24.2	7.2	8.4	1.3	0.9	0.08	0.041
5/24/2007	2	24.2	6.9	8.3	1.4	1.0	0.06	0.043
5/24/2007	3	24.7	8.6	9.0	1.7	1.3	0.14	0.051
5/24/2007	3	24.7	8.3	8.9	1.9	1.5	0.14	0.053
5/24/2007	3	24.9	9.2	8.9	2.0	1.6	0.12	0.046
5/24/2007	4	26.6	10.4	9.5	1.6	1.2	0.04	0.013

Continued Date	Site #	Temp (C)	Dissolved Oxygen (mg/L)	pH	NO_3^- -N (mg/L)	Correction NO_3^- -N (mg/L) *	PO_4^{3-} -P (mg/L)	NO_2^- -N (mg/L)
5/24/2007	4	26.6	11.5	9.6	1.6	1.2	0.05	0.016
5/24/2007	4	26.7	11.3	9.5	1.7	1.3	0.04	0.014
6/7/2007	1	24.2	5.6	7.9	0.8	0.4	0.35	0.050
6/7/2007	1	24.2	5.9	7.8	0.9	0.5	0.3	0.051
6/7/2007	1	24.3	5.6	7.7	0.9	0.5	0.11	0.051
6/7/2007	2	24.1	4.5	8.4	0.8	0.4	0.32	0.035
6/7/2007	2	24.1	4.6	8.0	0.7	0.3	0.26	0.035
6/7/2007	2	24.2	4.9	7.9	0.8	0.4	0.21	0.034
6/7/2007	3	24.8	4.1	8.4	0.7	0.3	0.23	0.023
6/7/2007	3	24.9	4.4	8.2	0.6	0.2	0.19	0.023
6/7/2007	3	24.6	5.7	7.9	0.7	0.3	0.22	0.023
6/7/2007	4	25.4	7.6	8.4	0.6	0.2	0.14	0.011
6/7/2007	4	25.4	7.3	8.2	0.6	0.2	0.19	0.009
6/7/2007	4	25.5	7.6	8.1	0.5	0.1	0.13	0.011
6/27/2007	1	28.0	8.0	8.1	0.9	0.5	0.07	0.033
6/27/2007	1	28.2	5.8	8.0	0.9	0.5	0.06	0.032
6/27/2007	1	28.1	6.7	7.9	0.9	0.5	0.06	0.033
6/27/2007	2	28.5	6.0	8.4	0.9	0.5	0.07	0.063
6/27/2007	2	27.9	6.5	8.2	0.9	0.5	0.06	0.063
6/27/2007	2	28.4	5.6	8.0	0.9	0.5	0.07	0.048
6/27/2007	3	29.2	8.0	8.7	0.7	0.3	0.06	0.019
6/27/2007	3	29.2	8.2	8.6	0.8	0.4	0.07	0.023
6/27/2007	3	29.4	8.8	8.6	0.7	0.3	0.07	0.020
6/27/2007	4	31.0	10.1	9.1	0.7	0.3	0.05	0.021
6/27/2007	4	31.0	9.7	9.0	0.7	0.3	0.08	0.025

Continued Date	Site #	Temp (C)	Dissolved Oxygen (mg/L)	pH	NO_3^- -N (mg/L)	Correction NO_3^- -N (mg/L) *	PO_4^{3-} -P (mg/L)	NO_2^- -N (mg/L)
6/27/2007	4	31.1	9.2	9.1	0.7	0.3	0.04	0.020
7/12/2007	1	28.0	6.6	8.5	1.0	0.6	0.14	0.033
7/12/2007	1	28.0	6.9	8.1	1.0	0.6	0.1	0.034
7/12/2007	1	28.1	6.6	7.9	1.0	0.6	0.07	0.034
7/12/2007	2	27.9	4.6	8.8	1.0	0.6	0.06	0.031
7/12/2007	2	27.9	6.0	8.5	0.9	0.5	0.08	0.032
7/12/2007	2	27.9	5.8	8.3	1.0	0.6	0.08	0.032
7/12/2007	3	27.3	5.7	8.6	0.7	0.3	0.08	0.013
7/12/2007	3	27.5	6.0	8.4	0.8	0.4	0.07	0.014
7/12/2007	3	27.5	6.7	8.1	0.7	0.3	0.08	0.015
7/12/2007	4	28.8	7.6	8.6	0.6	0.2	0.13	0.011
7/12/2007	4	28.8	8.0	8.6	0.7	0.3	0.08	0.010
7/12/2007	4	28.8	7.7	8.5	0.7	0.3	0.08	0.010
7/26/2007	1	25.3	7.3	8.1	0.9	0.5	0.11	0.045
7/26/2007	1	25.3	7.3	8.2	0.9	0.5	0.11	0.046
7/26/2007	1	25.5	7.0	8.0	0.9	0.5	0.09	0.046
7/26/2007	2	25.3	5.9	7.8	0.8	0.4	0.07	0.031
7/26/2007	2	25.3	5.6	7.7	0.8	0.4	0.08	0.031
7/26/2007	2	25.5	5.8	7.7	0.8	0.4	0.07	0.031
7/26/2007	3	25.4	8.3	8.3	0.6	0.2	0.09	0.014
7/26/2007	3	25.2	8.5	8.3	0.6	0.2	0.09	0.014
7/26/2007	3	25.9	8.2	8.2	0.7	0.3	0.07	0.013
7/26/2007	4	26.2	8.0	8.4	0.7	0.3	0.1	0.008
7/26/2007	4	26.2	7.9	8.3	0.7	0.3	0.08	0.009
7/26/2007	4	26.3	7.7	8.3	0.6	0.2	0.09	0.009

Continued Date	Site #	Temp (C)	Dissolved Oxygen (mg/L)	pH	NO_3^- -N (mg/L)	Correction NO_3^- -N (mg/L) *	PO_4^{3-} -P (mg/L)	NO_2^- -N (mg/L)
8/9/2007	1	29.7	8.0	7.6	0.9	0.5	0.1	0.017
8/9/2007	1	29.7	7.9	7.6	0.9	0.5	0.12	0.018
8/9/2007	1	29.7	8.0	7.7	0.8	0.4	0.09	0.019
8/9/2007	2	29.9	6.9	8.1	0.8	0.4	0.08	0.017
8/9/2007	2	29.9	6.9	8.1	0.9	0.5	0.07	0.016
8/9/2007	2	29.9	6.7	8.2	0.8	0.4	0.07	0.016
8/9/2007	3	30.6	8.2	8.2	0.8	0.4	0.07	0.010
8/9/2007	3	30.6	8.2	8.2	0.7	0.3	0.06	0.011
8/9/2007	3	30.5	7.8	8.2	0.7	0.3	0.06	0.010
8/9/2007	4	31.2	8.2	8.3	0.7	0.3	0.08	0.010
8/9/2007	4	31.3	8.4	8.2	0.7	0.3	0.08	0.010
8/9/2007	4	31.3	7.6	8.2	0.8	0.4	0.06	0.012
8/23/2007	1	26.3	5.4	8.1	0.9	0.5	0.08	0.055
8/23/2007	1	26.3	5.5	7.9	1.0	0.6	0.07	0.049
8/23/2007	1	26.2	5.3	7.8	1.1	0.7	0.08	0.047
8/23/2007	2	26.7	4.4	8.1	0.9	0.5	0.06	0.027
8/23/2007	2	26.7	4.7	7.9	0.9	0.5	0.07	0.029
8/23/2007	2	26.7	3.8	7.8	1.0	0.6	0.07	0.026
8/23/2007	3	27.5	3.5	8.2	0.8	0.4	0.04	0.018
8/23/2007	3	27.4	4.3	8.0	0.8	0.4	0.04	0.018
8/23/2007	3	27.4	4.0	7.9	0.8	0.4	0.04	0.018
8/23/2007	4	27.7	5.0	8.2	0.8	0.4	0.05	0.021
8/23/2007	4	27.7	4.8	8.1	0.7	0.3	0.06	0.017
8/23/2007	4	27.7	4.7	8.0	0.8	0.4	0.05	0.023
9/6/2007	1	23.9	5.4	7.2	1.2	0.8	0.11	0.108

Continued Date	Site #	Temp (C)	Dissolved Oxygen (mg/L)	pH	NO_3^- -N (mg/L)	Correction NO_3^- -N (mg/L) *	PO_4^{3-} -P (mg/L)	NO_2^- -N (mg/L)
9/6/2007	1	23.9	5.6	7.1	1.2	0.8	0.14	0.112
9/6/2007	1	23.8	5.6	7.0	1.1	0.7	0.13	0.111
9/6/2007	2	24.4	4.7	7.5	1.2	0.8	0.11	0.077
9/6/2007	2	24.3	4.7	7.3	1.1	0.7	0.14	0.077
9/6/2007	2	24.3	5.8	7.4	1.2	0.8	0.08	0.086
9/6/2007	3	24.2	6.0	7.4	1.0	0.6	0.08	0.053
9/6/2007	3	24.2	5.2	7.3	1.0	0.6	0.13	0.055
9/6/2007	3	24.2	5.4	7.3	1.1	0.7	0.12	0.055
9/6/2007	4	24.1	6.9	7.5	1.1	0.7	0.1	0.028
9/6/2007	4	24.1	7.0	7.4	1.1	0.7	0.13	0.026
9/6/2007	4	24.1	7.1	7.4	1.1	0.7	0.13	0.025
9/20/2007	1	21.4	6.0	7.2	1.0	0.6	0.08	0.042
9/20/2007	1	21.3	6.4	7.2	1.0	0.6	0.13	0.039
9/20/2007	1	21.4	5.6	7.2	1.0	0.6	0.06	0.040
9/20/2007	2	22.0	4.8	7.4	1.0	0.6	0.07	0.047
9/20/2007	2	21.9	5.5	7.3	1.1	0.7	0.09	0.047
9/20/2007	2	22.0	5.5	7.2	1.1	0.7	0.07	0.047
9/20/2007	3	21.4	6.4	7.4	0.9	0.5	0.05	0.018
9/20/2007	3	21.4	6.7	7.3	0.9	0.5	0.07	0.017
9/20/2007	3	21.4	6.3	7.3	0.9	0.5	0.07	0.016
9/20/2007	4	21.1	7.1	7.3	0.8	0.4	0.03	0.013
9/20/2007	4	21.1	7.4	7.3	0.8	0.4	0.04	0.011
9/20/2007	4	21.1	7.1	7.3	0.9	0.5	0.03	0.015
10/5/2007	1	22.7	6.8	7.2	1.2	0.8	0.11	0.084
10/5/2007	1	22.7	5.9	7.1	1.3	0.9	0.19	0.091

Continued Date	Site #	Temp (C)	Dissolved Oxygen (mg/L)	pH	NO_3^- -N (mg/L)	Correction NO_3^- -N (mg/L) *	PO_4^{3-} -P (mg/L)	NO_2^- -N (mg/L)
10/5/2007	1	22.7	6.2	7.0	1.2	0.8	0.15	0.086
10/5/2007	2	23.3	6.3	7.7	1.2	0.8	0.11	0.056
10/5/2007	2	23.3	6.4	7.5	1.2	0.8	0.1	0.070
10/5/2007	2	23.3	6.3	7.4	1.2	0.8	0.08	0.065
10/5/2007	3	23.2	4.7	7.4	0.9	0.5	0.09	0.021
10/5/2007	3	23.2	4.0	7.3	1.0	0.6	0.1	0.038
10/5/2007	3	23.2	3.9	7.2	1.0	0.6	0.09	0.029
10/5/2007	4	23.3	5.8	7.4	0.7	0.3	0.05	0.011
10/5/2007	4	23.3	5.6	7.3	0.9	0.5	0.04	0.012
10/5/2007	4	23.3	5.6	7.2	0.8	0.4	0.03	0.011
10/19/2007	1	21.9	5.8	7.6	1.1	0.7	0.2	0.319
10/19/2007	1	21.9	5.7	7.6	1.1	0.7	0.17	0.324
10/19/2007	1	21.9	5.7	7.6	1.0	0.6	0.19	0.323
10/19/2007	2	22.4	4.4	7.2	1.1	0.7	0.19	0.253
10/19/2007	2	22.4	4.6	7.2	1.0	0.6	0.17	0.260
10/19/2007	2	22.4	4.7	7.2	1.0	0.6	0.16	0.262
10/19/2007	3	22.4	5.7	7.0	0.9	0.5	0.1	0.143
10/19/2007	3	22.4	6.3	7.0	0.9	0.5	0.08	0.143
10/19/2007	3	22.4	6.0	7.0	0.9	0.5	0.09	0.138
10/19/2007	4	22.3	8.5	6.8	0.8	0.4	0.11	0.045
10/19/2007	4	22.3	8.3	6.8	0.8	0.4	0.1	0.041
10/19/2007	4	22.3	8.5	6.8	0.7	0.3	0.11	0.042
11/1/2007	1	17.5	7.9	6.8	1.0	0.6	0.09	0.080
11/1/2007	1	17.5	8.0	6.8	1.0	0.6	0.06	0.081
11/1/2007	1	17.5	8.2	6.6	1.1	0.7	0.08	0.081

Continued Date	Site #	Temp (C)	Dissolved Oxygen (mg/L)	pH	NO_3^- -N (mg/L)	Correction NO_3^- -N (mg/L) *	PO_4^{3-} -P (mg/L)	NO_2^- -N (mg/L)
11/1/2007	2	18.4	6.2	7.2	0.9	0.5	0.05	0.075
11/1/2007	2	18.2	6.4	7.1	1.0	0.6	0.08	0.076
11/1/2007	2	18.3	6.6	7.1	1.0	0.6	0.09	0.075
11/1/2007	3	16.8	7.1	7.3	0.9	0.5	0.03	0.020
11/1/2007	3	16.8	8.0	7.2	0.8	0.4	0.06	0.021
11/1/2007	3	16.8	7.9	7.2	0.8	0.4	0.07	0.022
11/1/2007	4	16.3	9.0	7.1	0.8	0.4	0.03	0.015
11/1/2007	4	16.3	9.3	7.1	0.8	0.4	0.03	0.015
11/1/2007	4	16.3	9.0	7.1	0.8	0.4	0.05	0.012
11/15/2007	1	17.1	5.7	6.9	1.8	1.4	0.42	0.060
11/15/2007	1	17.1	5.4	6.8	2.1	1.7	0.41	0.061
11/15/2007	1	17.1	5.4	6.7	2.0	1.6	0.36	0.061
11/15/2007	2	17.4	6.4	7.0	2.1	1.7	0.39	0.059
11/15/2007	2	17.5	6.1	6.8	2.4	2.0	0.37	0.060
11/15/2007	2	17.5	6.4	6.7	2.3	1.9	0.37	0.066
11/15/2007	3	16.8	6.4	7.0	2.0	1.6	0.4	0.060
11/15/2007	3	16.8	6.6	6.8	1.7	1.3	0.38	0.065
11/15/2007	3	16.7	6.6	6.7	1.8	1.4	0.41	0.063
11/15/2007	4	16.6	6.7	6.8	2.0	1.6	0.35	0.064
11/15/2007	4	16.6	6.8	6.8	2.6	2.2	0.37	0.062
11/15/2007	4	16.6	6.7	6.7	2.6	2.2	0.36	0.066
11/29/2007	1	13.2	7.8	7.2	0.9	0.5	0.2	0.021
11/29/2007	1	13.2	8.0	7.0	0.9	0.5	0.04	0.021
11/29/2007	1	13.2	7.5	6.9	0.9	0.5	0.05	0.021
11/29/2007	2	13.5	7.7	7.3	0.8	0.4	0.06	0.016

Continued Date	Site #	Temp (C)	Dissolved Oxygen (mg/L)	pH	NO_3^- -N (mg/L)	Correction NO_3^- -N (mg/L) *	PO_4^{3-} -P (mg/L)	NO_2^- -N (mg/L)
11/29/2007	2	13.5	7.2	7.0	0.9	0.5	0.05	0.016
11/29/2007	2	13.5	6.9	7.0	0.9	0.5	0.04	0.016
11/29/2007	3	12.0	8.0	7.3	0.7	0.3	0.06	0.008
11/29/2007	3	12.0	8.6	7.1	0.7	0.3	0.04	0.009
11/29/2007	3	12.0	8.1	7.1	0.7	0.3	0.05	0.009
11/29/2007	4	11.9	8.8	7.2	0.7	0.3	0.04	0.006
11/29/2007	4	11.9	9.2	7.1	0.7	0.3	0.04	0.007
11/29/2007	4	11.9	9.2	7.1	0.8	0.4	0.04	0.007
12/13/2007	1	15.7	7.2	7.2	0.9	0.5	0.32	0.056
12/13/2007	1	15.7	7.9	7.1	0.9	0.5	0.28	0.055
12/13/2007	1	15.8	7.6	6.8	0.9	0.5	0.29	0.057
12/13/2007	2	15.8	6.2	7.1	0.9	0.5	0.13	0.052
12/13/2007	2	15.8	6.0	7.0	0.9	0.5	0.13	0.054
12/13/2007	2	15.8	6.9	7.0	0.9	0.5	0.1	0.052
12/13/2007	3	15.0	6.5	7.3	0.8	0.4	0.09	0.061
12/13/2007	3	15.0	7.8	7.2	0.8	0.4	0.08	0.061
12/13/2007	3	15.0	8.3	7.1	0.9	0.5	0.08	0.061
12/13/2007	4	14.9	9.0	7.5	0.8	0.4	0.04	0.035
12/13/2007	4	14.9	9.5	7.4	0.8	0.4	0.04	0.033
12/13/2007	4	14.9	8.9	7.3	0.8	0.4	0.04	0.035
12/28/2007	1	Due to an error on the hydro lab screen, reading Check H20/DS3, no samples could be taken.			1.2	0.8	0.09	0.026
12/28/2007	1				1.2	0.8	0.1	0.027
12/28/2007	1				1.3	0.9	0.1	0.027
12/28/2007	2				1.3	0.9	0.11	0.027
12/28/2007	2				1.3	0.9	0.09	0.028

Continued Date	Site #	Temp (C)	Dissolved Oxygen (mg/L)	pH	NO_3^- -N (mg/L)	Correction NO_3^- -N (mg/L) *	PO_4^{3-} -P (mg/L)	NO_2^- -N (mg/L)
12/28/2007	2				1.2	0.8	0.09	0.028
12/28/2007	3				1.2	0.8	0.1	0.025
12/28/2007	3	Due to an error on the hydro lab screen, reading Check H20/DS3, no samples could be taken.			1.2	0.8	0.1	0.025
12/28/2007	3				1.5	1.1	0.09	0.026
12/28/2007	4				1.3	0.9	0.13	0.030
12/28/2007	4				1.3	0.9	0.11	0.033
12/28/2007	4				1.3	0.9	0.11	0.030
1/10/2008	1				0.9	0.5	0.18	0.051
1/10/2008	1				0.9	0.5	0.13	0.052
1/10/2008	1				0.9	0.5	0.16	0.045
1/10/2008	2				0.9	0.5	0.05	0.033
1/10/2008	2				0.9	0.5	0.07	0.033
1/10/2008	2	Both hydro labs are still out of order, so no readings could be taken at any of the sites. Last week of sampling.			0.9	0.5	0.09	0.034
1/10/2008	3				0.8	0.4	0.07	0.061
1/10/2008	3				0.9	0.5	0.07	0.066
1/10/2008	3				0.8	0.4	0.08	0.062
1/10/2008	4				0.8	0.4	0.05	0.049
1/10/2008	4				0.8	0.4	0.04	0.048
1/10/2008	4				0.9	0.5	0.04	0.048

* Correction for NO_3^-: Needed for every new packet of Nitra Ver 5 Chemicals 25ml DI water plus a powder packet of Nitra Ver 5. Analyzed in the spectrophotometer as a regular sample. The reading was 0.4 mg/L. This is to be subtracted from every reading using the Nitra Ver 5 Packets.

APPENDIX B

LEAF MASS PER LEAF PACK & BRICK DATABASE

Leaf Pack #	Leaf Pack Total Dry Mass (g)	Brick #	Site #
1	0.0943	1	4
2	0.0978	1	4
3	0.1057	1	4
4	0.1170	2	4
5	0.1098	2	4
6	0.1194	2	4
7	0.1079	3	4
8	0.1298	3	4
9	0.1092	3	4
10	0.1147	4	4
11	0.1131	4	4
12	0.1220	4	4
13	0.1307	5	4
14	0.1142	5	4
15	0.1062	5	4
16	0.1227	6	4
17	0.0699	6	4
18	0.1094	6	4
19	0.1336	7	4
20	0.0805	7	4
21	0.1024	7	4
22	0.0774	8	4
23	0.0769	9	3
24	0.0827	9	3
25	0.1337	9	3
26	0.1302	10	3
27	0.1320	10	3
28	0.1308	10	3
29	0.1217	11	3
30	0.1199	11	3
31	0.1127	11	3
32	0.1249	12	3
33	0.0832	12	3
34	0.1006	12	3
35	0.1019	13	3

Continued Leaf Pack #	Leaf Pack Total Dry Mass (g)	Brick #	Site #
36	0.1011	13	3
37	0.0898	13	3
38	0.0920	14	3
39	0.1109	14	3
40	0.1298	14	3
41	0.1102	15	3
42	0.0949	15	3
43	0.1002	15	3
44	0.0992	16	3
45	0.0863	17	2
46	0.0932	17	2
47	0.0942	17	2
48	0.0941	18	2
49	0.1100	18	2
50	0.1118	18	2
51	0.0885	19	2
52	0.1056	19	2
53	0.1241	19	2
54	0.1108	20	2
55	0.0996	20	2
56	0.0836	20	2
57	0.1211	21	2
58	0.1066	21	2
59	0.1226	21	2
60	0.1177	22	2
61	0.1150	22	2
62	0.1258	22	2
63	0.1254	23	2
64	0.1328	23	2
65	0.1376	23	2
66	0.1248	24	2
67	0.0820	25	1
68	0.1134	25	1
69	0.0864	25	1
70	0.1080	26	1
71	0.1190	26	1
72	0.0988	26	1
73	0.1098	27	1
74	0.1144	27	1
75	0.0806	27	1

Continued Leaf Pack #	Leaf Pack Total Dry Mass (g)	Brick #	Site #
76	0.0891	28	1
77	0.0854	28	1
78	0.1186	28	1
79	0.1064	29	1
80	0.0865	29	1
81	0.0875	29	1
82	0.1374	30	1
83	0.1663	30	1
84	0.1317	30	1
85	0.1508	31	1
86	0.2028	31	1
87	0.1331	31	1
88	0.1263	32	1
89	0.1316		
90	0.1334		
91	0.0809	Extra leaf packs, not used in leaf breakdown study	
92	0.0668		
93	0.0629		
94	0.0554		
95	0.0556		

APPENDIX C

LEAF BREAKDOWN CALCULATIONS

Date	Site #	Initial Leaf Mass (g)	Final Leaf Mass (g)	Total Mass Loss (g)
10/18/2007	1	0.1080	0.0306	0.0774
10/18/2007	1	0.1190	0.0485	0.0705
10/18/2007	1	0.0988	0.0344	0.0644
10/18/2007	2	0.0863	0.0791	0.0072
10/18/2007	2	0.0932	0.0236	0.0696
10/18/2007	2	0.0942	0.0428	0.0514
10/18/2007	3	0.0769	0.0436	0.0333
10/18/2007	3	0.0827	0.0312	0.0515
10/18/2007	3	0.1337	0.0515	0.0822
10/18/2007	4	0.0943	0.0297	0.0646
10/18/2007	4	0.0978	0.0731	0.0247
10/18/2007	4	0.1057	0.0496	0.0561
11/1/2007	1	0.1098	0.0852	0.0246
11/1/2007	1	0.1144	0.0967	0.0177
11/1/2007	1	0.0806	0.0362	0.0444
11/1/2007	2	0.0941	0.0943	-0.0002
11/1/2007	2	0.1100	0.0751	0.0349
11/1/2007	2	0.1118	0.0752	0.0366
11/1/2007	3	0.1302	0.0597	0.0705
11/1/2007	3	0.1320	0.0585	0.0735
11/1/2007	3	0.1308	0.0346	0.0962
11/1/2007	4	0.1170	0.0384	0.0786
11/1/2007	4	0.1098	0.0236	0.0862
11/1/2007	4	0.1194	0.0629	0.0565
11/16/2007	1	0.0891	0.0485	0.0406
11/16/2007	1	0.0854	0.0274	0.0580
11/16/2007	1	0.1186	0.0202	0.0984
11/16/2007	2	0.1254	0.0639	0.0615
11/16/2007	2	0.1328	0.0496	0.0832
11/16/2007	2	0.1376	0.0474	0.0902
11/16/2007	3	0.1217	0.0336	0.0881
11/16/2007	3	0.1199	0.0398	0.0801
11/16/2007	3	0.1127	0.0642	0.0485
11/16/2007	4	0.1079	0.0513	0.0566
11/16/2007	4	0.1298	0.0095	0.1203
11/16/2007	4	0.1092	0.0131	0.0961

Continued Date	Site #	Initial Leaf Mass (g)	Final Leaf Mass (g)	Total Mass Loss (g)
11/30/2007	1	0.1064	0.0555	0.0509
11/30/2007	1	0.0865	0.0019	0.0846
11/30/2007	1	0.0875	0.0303	0.0572
11/30/2007	2	0.0885	0.0193	0.0692
11/30/2007	2	0.1056	0.0383	0.0673
11/30/2007	2	0.1241	0.0166	0.1075
11/30/2007	3	0.1249	0.0145	0.1104
11/30/2007	3	0.0832	0.0466	0.0366
11/30/2007	3	0.1006	0.0331	0.0675
11/30/2007	4	0.1147	0.0521	0.0626
11/30/2007	4	0.1131	0.0253	0.0878
11/30/2007	4	0.1220	0.0289	0.0931
12/13/2007	1	0.1374	0.0584	0.0790
12/13/2007	1	0.1663	0.0188	0.1475
12/13/2007	1	0.1317	0.0292	0.1025
12/13/2007	2	0.1108	0.0322	0.0786
12/13/2007	2	0.0996	0.0197	0.0799
12/13/2007	2	0.0836	0.0489	0.0347
12/13/2007	3	0.1019	0.0073	0.0946
12/13/2007	3	0.1011	0.0644	0.0367
12/13/2007	3	0.0898	0.0278	0.0620
12/13/2007	4	0.1307	0.0025	0.1282
12/13/2007	4	0.1142	0.0089	0.1053
12/13/2007	4	0.1062	0.0002	0.1060

APPENDIX D

NUTRIENT SPIRALING DATABASE

Date	Time Period	Site #	NO_3^- -N (mg/L) **	NO_3^- -N AVERAGE	PO_4^{3-} -P (mg/L)	PO_4^{3-} -P AVERAGE	NO_2^- -N (mg/L)	NO_2^- -N AVERAGE
2/15/2007	Pre-Construction	1	0.8		0.06		0.013	
2/15/2007	Pre-Construction	1	0.7	0.7	0.06	0.06	0.021	0.019
2/15/2007	Pre-Construction	1	0.7		0.07		0.022	
2/15/2007	Pre-Construction	2	0.7		0.03		0.018	
2/15/2007	Pre-Construction	2	0.8	0.7	0.03	0.03	0.023	0.030
2/15/2007	Pre-Construction	2	0.7		0.02		0.048	
2/15/2007	Pre-Construction	3	0.7		0.03		0.016	
2/15/2007	Pre-Construction	3	0.7	0.7	0.03	0.03	0	0.011
2/15/2007	Pre-Construction	3	0.6		0.02		0.017	
2/15/2007	Pre-Construction	4	0.7		0.11		0.018	
2/15/2007	Pre-Construction	4	0.7	0.7	0.11	0.10	0.018	0.018
2/15/2007	Pre-Construction	4	0.7		0.09		0.018	
3/1/2007	Pre-Construction	1	0.7		0.04		0.029	
3/1/2007	Pre-Construction	1	0.7	0.7	0.02	0.03	0.03	0.030
3/1/2007	Pre-Construction	1	0.7		0.02		0.03	
3/1/2007	Pre-Construction	2	0.8		0.02		0.027	
3/1/2007	Pre-Construction	2	1.4	1.1	0.03	0.02	0.027	0.027
3/1/2007	Pre-Construction	2	1		0.01		0.026	
3/1/2007	Pre-Construction	3	0.8		0.07		0.026	
3/1/2007	Pre-Construction	3	0.7	0.7	0.09	0.07	0.026	0.026
3/1/2007	Pre-Construction	3	0.6		0.05		0.026	

Continued Date	Time Period	Site #	NO_3^--N (mg/L) **	NO_3^--N AVERAGE	PO_4^{3-}-P (mg/L)	PO_4^{3-}-P AVERAGE	NO_2^--N (mg/L)	NO_2^--N AVERAGE
3/1/2007	Pre-Construction	4	0.7		0.06		0.023	
3/1/2007	Pre-Construction	4	0.6	0.6	0.05	0.05	0.031	0.025
3/1/2007	Pre-Construction	4	0.6		0.05		0.022	
3/15/2007	Pre-Construction	1	0.6		0.03		0.052	
3/15/2007	Pre-Construction	1	0.7	0.7	0.03	0.03	0.054	0.054
3/15/2007	Pre-Construction	1	0.7		0.02		0.056	
3/15/2007	Pre-Construction	2	0.7		0.02		0.046	
3/15/2007	Pre-Construction	2	0.6	0.7	0.02	0.02	0.054	0.048
3/15/2007	Pre-Construction	2	0.7		0.01		0.045	
3/15/2007	Pre-Construction	3	0.6		0.01		0.028	
3/15/2007	Pre-Construction	3	0.6	0.6	0.01	0.01	0.041	0.032
3/15/2007	Pre-Construction	3	0.5		0.01		0.026	
3/15/2007	Pre-Construction	4	0.6		0.01		0.029	
3/15/2007	Pre-Construction	4	0.6	0.6	0.01	0.01	0.027	0.027
3/15/2007	Pre-Construction	4	0.6		0.01		0.026	
3/29/2007	Pre-Construction	1	0.6		0.04		0.058	
3/29/2007	Pre-Construction	1	0.6	0.6	0.04	0.03	0.06	0.065
3/29/2007	Pre-Construction	1	0.7		0.02		0.077	
3/29/2007	Pre-Construction	2	0.5		0.03		0.069	
3/29/2007	Pre-Construction	2	0.6	0.6	0.03	0.02	0.074	0.073
3/29/2007	Pre-Construction	2	0.6		0.01		0.076	
3/29/2007	Pre-Construction	3	0.6		0.04		0.052	
3/29/2007	Pre-Construction	3	0.7	0.7	0.04	0.04	0.054	0.051
3/29/2007	Pre-Construction	3	0.7		0.03		0.047	

Continued Date	Time Period	Site #	NO_3^- -N (mg/L) **	NO_3^- -N AVERAGE	PO_4^{3-} -P (mg/L)	PO_4^{3-} -P AVERAGE	NO_2^- -N (mg/L)	NO_2^- -N AVERAGE
3/29/2007	Pre-Construction	4	0.4		0.02		0.033	
3/29/2007	Pre-Construction	4	0.3	0.4	0.02	0.02	0.033	0.033
3/29/2007	Pre-Construction	4	0.5		0.03		0.032	
4/12/2007	Pre-Construction	1	0.5		0.08		0.057	
4/12/2007	Pre-Construction	1	0.5	0.5	0.08	0.08	0.053	0.055
4/12/2007	Pre-Construction	1	0.6		0.07		0.054	
4/12/2007	Pre-Construction	2	0.5		0.07		0.050	
4/12/2007	Pre-Construction	2	0.5	0.5	0.07	0.07	0.045	0.046
4/12/2007	Pre-Construction	2	0.5		0.06		0.043	
4/12/2007	Pre-Construction	3	0.4		0.06		0.045	
4/12/2007	Pre-Construction	3	0.4	0.4	0.06	0.06	0.046	0.046
4/12/2007	Pre-Construction	3	0.4		0.05		0.046	
4/12/2007	Pre-Construction	4	0.4		0.06		0.055	
4/12/2007	Pre-Construction	4	0.5	0.4	0.06	0.06	0.055	0.056
4/12/2007	Pre-Construction	4	0.3		0.05		0.057	
4/26/2007	Pre-Construction	1	0.5		0.11		0.113	
4/26/2007	Pre-Construction	1	0.5	0.5	0.11	0.11	0.115	0.115
4/26/2007	Pre-Construction	1	0.6		0.11		0.116	
4/26/2007	Pre-Construction	2	0.5		0.09		0.108	
4/26/2007	Pre-Construction	2	0.5	0.5	0.09	0.09	0.112	0.110
4/26/2007	Pre-Construction	2	0.5		0.09		0.111	
4/26/2007	Pre-Construction	3	0.6		0.06		0.138	
4/26/2007	Pre-Construction	3	0.6	0.6	0.07	0.06	0.140	0.138
4/26/2007	Pre-Construction	3	0.6		0.06		0.137	

Continued Date	Time Period	Site #	NO_3^- -N (mg/L) **	NO_3^- -N AVERAGE	PO_4^{3-} -P (mg/L)	PO_4^{3-} -P AVERAGE	NO_2^- -N (mg/L)	NO_2^- -N AVERAGE
4/26/2007	Pre-Construction	4	0.5		0.04		0.066	
4/26/2007	Pre-Construction	4	0.5	0.5	0.02	0.03	0.060	0.064
4/26/2007	Pre-Construction	4	0.5		0.04		0.065	
5/10/2007	Construction	1	0.9		0.35		0.270	
5/10/2007	Construction	1	1	0.9	0.29	0.31	0.266	0.267
5/10/2007	Construction	1	0.8		0.30		0.266	
5/10/2007	Construction	2	1.6		0.28		0.220	
5/10/2007	Construction	2	1.6	1.6	0.25	0.26	0.214	0.217
5/10/2007	Construction	2	1.5		0.26		0.218	
5/10/2007	Construction	3	0.7		0.07		0.155	
5/10/2007	Construction	3	0.6	0.6	0.07	0.07	0.156	0.156
5/10/2007	Construction	3	0.6		0.07		0.157	
5/10/2007	Construction	4	0.6		0.07		0.097	
5/10/2007	Construction	4	0.5	0.6	0.06	0.06	0.106	0.103
5/10/2007	Construction	4	0.7		0.06		0.105	
5/24/2007	Construction	1	0.8		0.09		0.034	
5/24/2007	Construction	1	1.3	0.9	0.06	0.06	0.030	0.032
5/24/2007	Construction	1	0.7		0.04		0.032	
5/24/2007	Construction	2	0.9		0.05		0.037	
5/24/2007	Construction	2	0.9	0.9	0.08	0.06	0.041	0.040
5/24/2007	Construction	2	1		0.06		0.043	
5/24/2007	Construction	3	1.3		0.14		0.051	
5/24/2007	Construction	3	1.5	1.5	0.14	0.13	0.053	0.050
5/24/2007	Construction	3	1.6		0.12		0.046	

Continued Date	Time Period	Site #	NO_3^--N (mg/L) **	NO_3^--N AVERAGE	PO_4^{3-}-P (mg/L)	PO_4^{3-}-P AVERAGE	NO_2^--N (mg/L)	NO_2^--N AVERAGE
5/24/2007	Construction	4	1.2		0.04		0.013	
5/24/2007	Construction	4	1.2	1.2	0.05	0.04	0.016	0.014
5/24/2007	Construction	4	1.3		0.04		0.014	
6/7/2007	Construction	1	0.4		0.35		0.050	
6/7/2007	Construction	1	0.5	0.5	0.3	0.25	0.051	0.051
6/7/2007	Construction	1	0.5		0.11		0.051	
6/7/2007	Construction	2	0.4		0.32		0.035	
6/7/2007	Construction	2	0.3	0.4	0.26	0.26	0.035	0.035
6/7/2007	Construction	2	0.4		0.21		0.034	
6/7/2007	Construction	3	0.3		0.23		0.023	
6/7/2007	Construction	3	0.2	0.3	0.19	0.21	0.023	0.023
6/7/2007	Construction	3	0.3		0.22		0.023	
6/7/2007	Construction	4	0.2		0.14		0.011	
6/7/2007	Construction	4	0.2	0.2	0.19	0.15	0.009	0.010
6/7/2007	Construction	4	0.1		0.13		0.011	
6/27/2007	Construction	1	0.5		0.07		0.033	
6/27/2007	Construction	1	0.5	0.5	0.06	0.06	0.032	0.033
6/27/2007	Construction	1	0.5		0.06		0.033	
6/27/2007	Construction	2	0.5		0.07		0.063	
6/27/2007	Construction	2	0.5	0.5	0.06	0.07	0.063	0.058
6/27/2007	Construction	2	0.5		0.07		0.048	
6/27/2007	Construction	3	0.3		0.06		0.019	
6/27/2007	Construction	3	0.4	0.3	0.07	0.07	0.023	0.021
6/27/2007	Construction	3	0.3		0.07		0.020	

Continued Date	Time Period	Site #	NO_3^- -N (mg/L) **	NO_3^- -N AVERAGE	PO_4^{3-} -P (mg/L)	PO_4^{3-} -P AVERAGE	NO_2^- -N (mg/L)	NO_2^- -N AVERAGE
6/27/2007	Construction	4	0.3		0.05		0.021	
6/27/2007	Construction	4	0.3	0.3	0.08	0.06	0.025	0.022
6/27/2007	Construction	4	0.3		0.04		0.020	
7/12/2007	Construction	1	0.6		0.14		0.033	
7/12/2007	Construction	1	0.6	0.6	0.1	0.10	0.034	0.034
7/12/2007	Construction	1	0.6		0.07		0.034	
7/12/2007	Construction	2	0.6		0.06		0.031	
7/12/2007	Construction	2	0.5	0.6	0.08	0.07	0.032	0.032
7/12/2007	Construction	2	0.6		0.08		0.032	
7/12/2007	Construction	3	0.3		0.08		0.013	
7/12/2007	Construction	3	0.4	0.3	0.07	0.08	0.014	0.014
7/12/2007	Construction	3	0.3		0.08		0.015	
7/12/2007	Construction	4	0.2		0.13		0.011	
7/12/2007	Construction	4	0.3	0.3	0.08	0.10	0.010	0.010
7/12/2007	Construction	4	0.3		0.08		0.010	
7/26/2007	Construction	1	0.5		0.11		0.045	
7/26/2007	Construction	1	0.5	0.5	0.11	0.10	0.046	0.046
7/26/2007	Construction	1	0.5		0.09		0.046	
7/26/2007	Construction	2	0.4		0.07		0.031	
7/26/2007	Construction	2	0.4	0.4	0.08	0.07	0.031	0.031
7/26/2007	Construction	2	0.4		0.07		0.031	
7/26/2007	Construction	3	0.2		0.09		0.014	
7/26/2007	Construction	3	0.2	0.2	0.09	0.08	0.014	0.014
7/26/2007	Construction	3	0.3		0.07		0.013	

Continued Date	Time Period	Site #	NO_3^- -N (mg/L) **	NO_3^- -N AVERAGE	PO_4^{3-} -P (mg/L)	PO_4^{3-} -P AVERAGE	NO_2^- -N (mg/L)	NO_2^- -N AVERAGE
7/26/2007	Construction	4	0.3		0.1		0.008	
7/26/2007	Construction	4	0.3	0.3	0.08	0.09	0.009	0.009
7/26/2007	Construction	4	0.2		0.09		0.009	
8/9/2007	Construction	1	0.5		0.1		0.017	
8/9/2007	Construction	1	0.5	0.5	0.12	0.10	0.018	0.018
8/9/2007	Construction	1	0.4		0.09		0.019	
8/9/2007	Construction	2	0.4		0.08		0.017	
8/9/2007	Construction	2	0.5	0.4	0.07	0.07	0.016	0.016
8/9/2007	Construction	2	0.4		0.07		0.016	
8/9/2007	Construction	3	0.4		0.07		0.010	
8/9/2007	Construction	3	0.3	0.3	0.06	0.06	0.011	0.010
8/9/2007	Construction	3	0.3		0.06		0.010	
8/9/2007	Construction	4	0.3		0.08		0.010	
8/9/2007	Construction	4	0.3	0.3	0.08	0.07	0.010	0.011
8/9/2007	Construction	4	0.4		0.06		0.012	
8/23/2007	Construction	1	0.5		0.08		0.055	
8/23/2007	Construction	1	0.6	0.6	0.07	0.08	0.049	0.050
8/23/2007	Construction	1	0.7		0.08		0.047	
8/23/2007	Construction	2	0.5		0.06		0.027	
8/23/2007	Construction	2	0.5	0.5	0.07	0.07	0.029	0.027
8/23/2007	Construction	2	0.6		0.07		0.026	
8/23/2007	Construction	3	0.4		0.04		0.018	
8/23/2007	Construction	3	0.4	0.4	0.04	0.04	0.018	0.018
8/23/2007	Construction	3	0.4		0.04		0.018	

Continued Date	Time Period	Site #	NO_3^- -N (mg/L) **	NO_3^- -N AVERAGE	PO_4^{3-} -P (mg/L)	PO_4^{3-} -P AVERAGE	NO_2^- -N (mg/L)	NO_2^- -N AVERAGE
8/23/2007	Construction	4	0.4		0.05		0.021	
8/23/2007	Construction	4	0.3	0.4	0.06	0.05	0.017	0.020
8/23/2007	Construction	4	0.4		0.05		0.023	
9/6/2007	Construction	1	0.8		0.11		0.108	
9/6/2007	Construction	1	0.8	0.8	0.14	0.13	0.112	0.110
9/6/2007	Construction	1	0.7		0.13		0.111	
9/6/2007	Construction	2	0.8		0.11		0.077	
9/6/2007	Construction	2	0.7	0.8	0.14	0.11	0.077	0.080
9/6/2007	Construction	2	0.8		0.08		0.086	
9/6/2007	Construction	3	0.6		0.08		0.053	
9/6/2007	Construction	3	0.6	0.6	0.13	0.11	0.055	0.054
9/6/2007	Construction	3	0.7		0.12		0.055	
9/6/2007	Construction	4	0.7		0.1		0.028	
9/6/2007	Construction	4	0.7	0.7	0.13	0.12	0.026	0.026
9/6/2007	Construction	4	0.7		0.13		0.025	
9/20/2007	Construction	1	0.6		0.08		0.042	
9/20/2007	Construction	1	0.6	0.6	0.13	0.09	0.039	0.040
9/20/2007	Construction	1	0.6		0.06		0.040	
9/20/2007	Construction	2	0.6		0.07		0.047	
9/20/2007	Construction	2	0.7	0.7	0.09	0.08	0.047	0.047
9/20/2007	Construction	2	0.7		0.07		0.047	
9/20/2007	Construction	3	0.5		0.05		0.018	
9/20/2007	Construction	3	0.5	0.5	0.07	0.06	0.017	0.017
9/20/2007	Construction	3	0.5		0.07		0.016	

Continued Date	Time Period	Site #	NO_3^- -N (mg/L) **	NO_3^- -N AVERAGE	PO_4^{3-} -P (mg/L)	PO_4^{3-} -P AVERAGE	NO_2^- -N (mg/L)	NO_2^- -N AVERAGE
9/20/2007	Construction	4	0.4		0.03		0.013	
9/20/2007	Construction	4	0.4	0.4	0.04	0.03	0.011	0.013
9/20/2007	Construction	4	0.5		0.03		0.015	
10/4/2007	Construction	1	0.8		0.11		0.084	
10/4/2007	Construction	1	0.9	0.8	0.19	0.15	0.091	0.087
10/4/2007	Construction	1	0.8		0.15		0.086	
10/4/2007	Construction	2	0.8		0.11		0.056	
10/4/2007	Construction	2	0.8	0.8	0.1	0.10	0.070	0.064
10/4/2007	Construction	2	0.8		0.08		0.065	
10/4/2007	Construction	3	0.5		0.09		0.021	
10/4/2007	Construction	3	0.6	0.6	0.1	0.09	0.038	0.029
10/4/2007	Construction	3	0.6		0.09		0.029	
10/4/2007	Construction	4	0.3		0.05		0.011	
10/4/2007	Construction	4	0.5	0.4	0.04	0.04	0.012	0.011
10/4/2007	Construction	4	0.4		0.03		0.011	
10/18/2007	Construction	1	0.7		0.2		0.319	
10/18/2007	Construction	1	0.7	0.7	0.17	0.19	0.324	0.322
10/18/2007	Construction	1	0.6		0.19		0.323	
10/18/2007	Construction	2	0.7		0.19		0.253	
10/18/2007	Construction	2	0.6	0.6	0.17	0.17	0.260	0.258
10/18/2007	Construction	2	0.6		0.16		0.262	
10/18/2007	Construction	3	0.5		0.1		0.143	
10/18/2007	Construction	3	0.5	0.5	0.08	0.09	0.143	0.141
10/18/2007	Construction	3	0.5		0.09		0.138	

Continued Date	Time Period	Site #	NO_3^- -N (mg/L) **	NO_3^- -N AVERAGE	PO_4^{3-} -P (mg/L)	PO_4^{3-} -P AVERAGE	NO_2^- -N (mg/L)	NO_2^- -N AVERAGE
10/18/2007	Construction	4	0.4		0.11		0.045	
10/18/2007	Construction	4	0.4	0.4	0.1	0.11	0.041	0.043
10/18/2007	Construction	4	0.3		0.11		0.042	
11/1/2007	Post-Construction	1	0.6		0.09		0.080	
11/1/2007	Post-Construction	1	0.6	0.6	0.06	0.08	0.081	0.081
11/1/2007	Post-Construction	1	0.7		0.08		0.081	
11/1/2007	Post-Construction	2	0.5		0.05		0.075	
11/1/2007	Post-Construction	2	0.6	0.6	0.08	0.07	0.076	0.075
11/1/2007	Post-Construction	2	0.6		0.09		0.075	
11/1/2007	Post-Construction	3	0.5		0.03		0.020	
11/1/2007	Post-Construction	3	0.4	0.4	0.06	0.05	0.021	0.021
11/1/2007	Post-Construction	3	0.4		0.07		0.022	
11/1/2007	Post-Construction	4	0.4		0.03		0.015	
11/1/2007	Post-Construction	4	0.4	0.4	0.03	0.04	0.015	0.014
11/1/2007	Post-Construction	4	0.4		0.05		0.012	
11/15/2007	Post-Construction	1	1.4		0.42		0.060	
11/15/2007	Post-Construction	1	1.7	1.6	0.41	0.40	0.061	0.061
11/15/2007	Post-Construction	1	1.6		0.36		0.061	
11/15/2007	Post-Construction	2	1.7		0.39		0.059	
11/15/2007	Post-Construction	2	2	1.9	0.37	0.38	0.060	0.062
11/15/2007	Post-Construction	2	1.9		0.37		0.066	
11/15/2007	Post-Construction	3	1.6		0.4		0.060	
11/15/2007	Post-Construction	3	1.3	1.4	0.38	0.40	0.065	0.063
11/15/2007	Post-Construction	3	1.4		0.41		0.063	

Continued Date	Time Period	Site #	NO_3^- -N (mg/L) **	NO_3^- -N AVERAGE	PO_4^{3-} -P (mg/L)	PO_4^{3-} -P AVERAGE	NO_2^- -N (mg/L)	NO_2^- -N AVERAGE
11/15/2007	Post-Construction	4	1.6		0.35		0.064	
11/15/2007	Post-Construction	4	2.2	2.0	0.37	0.36	0.062	0.064
11/15/2007	Post-Construction	4	2.2		0.36		0.066	
11/29/2007	Post-Construction	1	0.5		0.2		0.021	
11/29/2007	Post-Construction	1	0.5	0.5	0.04	0.10	0.021	0.021
11/29/2007	Post-Construction	1	0.5		0.05		0.021	
11/29/2007	Post-Construction	2	0.4		0.06		0.016	
11/29/2007	Post-Construction	2	0.5	0.5	0.05	0.05	0.016	0.016
11/29/2007	Post-Construction	2	0.5		0.04		0.016	
11/29/2007	Post-Construction	3	0.3		0.06		0.008	
11/29/2007	Post-Construction	3	0.3	0.3	0.04	0.05	0.009	0.009
11/29/2007	Post-Construction	3	0.3		0.05		0.009	
11/29/2007	Post-Construction	4	0.3		0.04		0.006	
11/29/2007	Post-Construction	4	0.3	0.3	0.04	0.04	0.007	0.007
11/29/2007	Post-Construction	4	0.4		0.04		0.007	
12/13/2007	Post-Construction	1	0.5		0.32		0.056	
12/13/2007	Post-Construction	1	0.5	0.5	0.28	0.30	0.055	0.056
12/13/2007	Post-Construction	1	0.5		0.29		0.057	
12/13/2007	Post-Construction	2	0.5		0.13		0.052	
12/13/2007	Post-Construction	2	0.5	0.5	0.13	0.12	0.054	0.053
12/13/2007	Post-Construction	2	0.5		0.1		0.052	
12/13/2007	Post-Construction	3	0.4		0.09		0.061	
12/13/2007	Post-Construction	3	0.4	0.4	0.08	0.08	0.061	0.061
12/13/2007	Post-Construction	3	0.5		0.08		0.061	

Continued Date	Time Period	Site #	NO_3^- -N (mg/L) **	NO_3^- -N AVERAGE	PO_4^{3-} -P (mg/L)	PO_4^{3-} -P AVERAGE	NO_2^- -N (mg/L)	NO_2^- -N AVERAGE
12/13/2007	Post-Construction	4	0.4		0.04		0.035	
12/13/2007	Post-Construction	4	0.4	0.4	0.04	0.04	0.033	0.034
12/13/2007	Post-Construction	4	0.4		0.04		0.035	
12/28/2007	Post-Construction	1	0.8		0.09		0.026	
12/28/2007	Post-Construction	1	0.8	0.8	0.1	0.10	0.027	0.027
12/28/2007	Post-Construction	1	0.9		0.1		0.027	
12/28/2007	Post-Construction	2	0.9		0.11		0.027	
12/28/2007	Post-Construction	2	0.9	0.9	0.09	0.10	0.028	0.028
12/28/2007	Post-Construction	2	0.8		0.09		0.028	
12/28/2007	Post-Construction	3	0.8		0.1		0.025	
12/28/2007	Post-Construction	3	0.8	0.9	0.1	0.10	0.025	0.025
12/28/2007	Post-Construction	3	1.1		0.09		0.026	
12/28/2007	Post-Construction	4	0.9		0.13		0.030	
12/28/2007	Post-Construction	4	0.9	0.9	0.11	0.12	0.033	0.031
12/28/2007	Post-Construction	4	0.9		0.11		0.030	
1/10/2008	Post-Construction	1	0.5		0.18		0.051	
1/10/2008	Post-Construction	1	0.5	0.5	0.13	0.16	0.052	0.049
1/10/2008	Post-Construction	1	0.5		0.16		0.045	
1/10/2008	Post-Construction	2	0.5		0.05		0.033	
1/10/2008	Post-Construction	2	0.5	0.5	0.07	0.07	0.033	0.033
1/10/2008	Post-Construction	2	0.5		0.09		0.034	
1/10/2008	Post-Construction	3	0.4		0.07		0.061	
1/10/2008	Post-Construction	3	0.5	0.4	0.07	0.07	0.066	0.063
1/10/2008	Post-Construction	3	0.4		0.08		0.062	

Continued Date	Time Period	Site #	NO_3^- -N (mg/L) **	NO_3^- -N AVERAGE	PO_4^{3-} -P (mg/L)	PO_4^{3-} -P AVERAGE	NO_2^- -N (mg/L)	NO_2^- -N AVERAGE
1/10/2008	Post-Construction	4	0.4		0.05		0.049	
1/10/2008	Post-Construction	4	0.4	0.4	0.04	0.04	0.048	0.048
1/10/2008	Post-Construction	4	0.5		0.04		0.048	

** The Corrected NO_3^- values were used in these calculations.

APPENDIX E

UPTAKE LENGTH CALCULATIONS

		Average Concentrations for Each Site		Uptake Lengths Between Sites (mg/L/km) **
Date	Nutrient	1	4	4-1
2/15/2007	NO_3^- -N	0.733	0.700	0.018
3/1/2007	NO_3^- -N	0.700	0.633	0.035
3/15/2007	NO_3^- -N	0.667	0.600	0.035
3/29/2007	NO_3^- -N	0.633	0.400	0.123
4/12/2007	NO_3^- -N	0.533	0.400	0.070
4/26/2007	NO_3^- -N	0.533	0.500	0.018
5/10/2007	NO_3^- -N	0.900	0.600	0.158
5/24/2007	NO_3^- -N	0.933	1.233	-0.158
6/7/2007	NO_3^- -N	0.467	0.167	0.158
6/27/2007	NO_3^- -N	0.500	0.300	0.105
7/12/2007	NO_3^- -N	0.600	0.267	0.175
7/26/2007	NO_3^- -N	0.500	0.267	0.123
8/9/2007	NO_3^- -N	0.467	0.333	0.070
8/23/2007	NO_3^- -N	0.600	0.367	0.123
9/6/2007	NO_3^- -N	0.767	0.700	0.035
9/20/2007	NO_3^- -N	0.600	0.433	0.088
10/4/2007	NO_3^- -N	0.833	0.400	0.228
10/18/2007	NO_3^- -N	0.667	0.367	0.158
11/1/2007	NO_3^- -N	0.633	0.400	0.123
11/15/2007	NO_3^- -N	1.567	2.000	-0.228
11/29/2007	NO_3^- -N	0.500	0.333	0.088
12/13/2007	NO_3^- -N	0.500	0.400	0.053
12/28/2007	NO_3^- -N	0.833	0.900	-0.035
1/10/2008	NO_3^- -N	0.500	0.433	0.035

Continued Date	Nutrient	Average Concentrations for Each Site 1	4	Uptake Lengths Between Sites (mg/L/km) ** 4-1
3/15/2007	PO_4^{3-} -P	0.027	0.010	0.009
3/29/2007	PO_4^{3-} -P	0.033	0.023	0.005
4/12/2007	PO_4^{3-} -P	0.077	0.057	0.011
4/26/2007	PO_4^{3-} -P	0.110	0.033	0.040
5/10/2007	PO_4^{3-} -P	0.313	0.063	0.132
5/24/2007	PO_4^{3-} -P	0.063	0.043	0.011
6/7/2007	PO_4^{3-} -P	0.253	0.153	0.053
6/27/2007	PO_4^{3-} -P	0.063	0.057	0.004
7/12/2007	PO_4^{3-} -P	0.103	0.097	0.004
7/26/2007	PO_4^{3-} -P	0.103	0.090	0.007
8/9/2007	PO_4^{3-} -P	0.103	0.073	0.016
8/23/2007	PO_4^{3-} -P	0.077	0.053	0 012
9/6/2007	PO_4^{3-} -P	0.127	0.120	0.004
9/20/2007	PO_4^{3-} -P	0.090	0.033	0.030
10/4/2007	PO_4^{3-} -P	0.150	0.040	0.058
10/18/2007	PO_4^{3-} -P	0.187	0.107	0.042
11/1/2007	PO_4^{3-} -P	0.077	0.037	0.021
11/15/2007	PO_4^{3-} -P	0.397	0.360	0.019
11/29/2007	PO_4^{3-} -P	0.097	0.040	0.030
12/13/2007	PO_4^{3-} -P	0.297	0.040	0.135
12/28/2007	PO_4^{3-} -P	0.097	0.117	-0.011
1/10/2008	PO_4^{3-} -P	0.157	0.043	0.060
2/15/2007	NO_2^- -N	0.019	0.018	0.000
3/1/2007	NO_2^- -N	0.030	0.025	0.002
3/15/2007	NO_2^- -N	0.054	0.027	0.014
3/29/2007	NO_2^- -N	0.065	0.033	0.017
4/12/2007	NO_2^- -N	0.055	0.056	-0.001
4/26/2007	NO_2^- -N	0.115	0.064	0.027

Continued Date	Nutrient	Average Concentrations for Each Site 1	4	Uptake Lengths Between Sites (mg/L/km) ** 4-1
6/7/2007	NO_2^- -N	0.051	0.010	0.021
6/27/2007	NO_2^- -N	0.033	0.022	0.006
7/12/2007	NO_2^- -N	0.034	0.010	0.012
7/26/2007	NO_2^- -N	0.046	0.009	0.019
8/9/2007	NO_2^- -N	0.018	0.011	0.004
8/23/2007	NO_2^- -N	0.050	0.020	0.016
9/6/2007	NO_2^- -N	0.110	0.026	0.044
9/20/2007	NO_2^- -N	0.040	0.013	0.014
10/4/2007	NO_2^- -N	0.087	0.011	0.040
10/18/2007	NO_2^- -N	0.322	0.043	0.147
11/1/2007	NO_2^- -N	0.081	0.014	0.035
11/15/2007	NO_2^- -N	0.061	0.064	-0.002
11/29/2007	NO_2^- -N	0.021	0.007	0.008
12/13/2007	NO_2^- -N	0.056	0.034	0.011
12/28/2007	NO_2^- -N	0.027	0.031	-0.002
1/10/2008	NO_2^- -N	0.049	0.048	0.001

** Uptake Lengths were calculated using the average concentrations of each site. The difference between the two sites was found and then divided by the distance between these sites.