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IMPACT OF A TURFGRASS SYSTEM ON NUTRIENT LOADINGS TO SURFACE WATER[1]

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ABSTRACT: Turfgrass systems are one of the most intensively managed land uses in the United States. Establishment and maintenance of high quality turfgrass usually implies substantial inputs of water, nutrients, and pesticides. The focus of this work was to quantify the concentration and loading of a typically maintained municipal turfgrass environment on surface water. Water quantity and quality data were collected from a golf course in Austin, Texas, and analyzed for a 13-month period from March 20, 1998, to April 30, 1999. Twenty-two precipitation events totaling 722 mm, produced an estimated 98 mm of runoff. Nutrient analysis of surface runoff exiting the course exhibited a statistically significant ($p < 0.05$) increase in median nitrate plus nitrite nitrogen (NO_3+NO_2-N) concentration compared to runoff entering the course, a statistically significant decrease in ammonia nitrogen (NH_4-N), but no difference in ortho-phosphate (PO_4-P). During the 13-month period, storm runoff contributed an estimated 2.3 kg/ha of NO_3+NO_2-N and 0.33 kg/ha of PO_4-P to the stream. Storm flow accounted for the attenuation of 0.12 kg/ha of NH_4-N. Baseflow nutrient analysis showed a statistically significant increase in median NO_3+NO_2-N, a significant reduction in NH_4-N, and no change in PO_4-P. Estimated NO_3+NO_2-N mass in the baseflow was calculated as 4.7 kg/ha. PO_4-P losses were estimated at 0.06 kg/ha, while 0.8 kg/ha of NH_4-N were attenuated in baseflow over the study period. Even though nutrient concentrations exiting the system rarely exceeded nutrient screening levels, this turfgrass environment did contribute increased NO_3+NO_2-N and PO_4-P loads to the stream. This emphasizes the need for parallel studies where management intensity, soil, and climate differ from this study and for golf course managers to utilize an integrated management program to protect water quality while maintaining healthy turfgrass systems.

(KEY TERMS: water quality; hydrology; urban landscape; runoff.)

INTRODUCTION

Turfgrass systems, including golf courses, turf farms, city parks, and lawns, are one of the most intensively managed land uses in the United States. Turfgrass establishment and maintenance usually implies substantial inputs of water, nutrients, and often pesticides. The impact of these inputs on water quality and quantity is of vital importance in addressing the potential contribution of turfgrass systems to water quality degradation.

Environmentally sound management of golf course turfgrass provides both public and private facilities with environmental, cultural, and economic benefits. According to the National Golf Foundation (1998), over 16,000 golf courses are in operation in the United States with an average of 1.2 new courses opening every day. The public demands that golf course managers maintain high quality turfgrass on golf courses, but also to protect water and soil resources in the vicinity of these facilities (Balogh *et al.,* 1992; Beard and Greene, 1994). Management of existing golf courses and construction of new facilities often is a lightning rod for environmental and water quality concern (Balogh *et al.,* 1992). Water quality, resource allocation, and environmental issues specifically related to turfgrass management on existing and proposed facilities include:

- Potential offsite movement of nutrients and pesticides into surface water and ground water.
- Direct exposure of beneficial soil organisms, wildlife, and aquatic systems to pesticides and/or fertilizers.
- Loss of soil and sediment during golf course renovation, construction, and from poorly drained areas, shaded spots, and high-traffic areas on established golf courses.

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- Disturbance of the water balance during golf course development or renovation by converting vegetation, changing topography, and increasing the use of water for irrigation.
- Excessive use of potable water for turfgrass irrigation in arid and semiarid climates.
- Disturbance and loss of wetlands.
- Disturbance and change of existing land use patterns.

The challenge faced by the golf course superintendents and owners is to select environmentally sound and economically feasible plans to resolve these potential problems. Using a risk reduction approach, most golf course managers are using site specific Turfgrass Management System (TMS) plans to maintain high quality turfgrass and protect water and soil resources. TMS plans include integrated best management practices involving irrigation, fertilization, pest and disease control, soil and water conservation practices, and other agronomic practices related to turfgrass management.

Previous studies, including Birdwell (1995) and Gross *et al.* (1990), used turfgrass plots or isolated sites to investigate the impact of management on turfgrass. Birdwell (1995) conducted runoff analysis over three months during the spring of 1995 on green and fairway sites on a private golf course in Central Texas. This study resulted in complete hydrology data sets for one green and one fairway. The 0.025 ha green, with a loamy sand soil and a maximum slope of 10 percent, produced 11 percent of the precipitation as runoff for the study period, while the 1.573 ha fairway, with a clay loam soil and a maximum slope of 11 percent, produced 14 percent of precipitation as runoff. Over the three-month period, 0.13 kg/ha of NO_3-N left the green in runoff (0.08 percent of applied N), and 0.24 kg/ha of NO_3-N left the fairway in runoff (0.15 percent of applied N). Maximum NO_3-N concentrations in runoff were 0.5 mg/L from the green and 6.4 mg/L from the fairway. Gross *et al.* (1990) reported similar findings from sandy loam turf grass plots in Maryland over a two-year period. The plots received 220 kg N/ha/yr as liquid and granular urea distributed over five applications. NO_3-N losses in runoff ranged from 0.035 to 0.084 kg/ha/yr, and PO_4-P losses in runoff ranged from 0.008 to 0.123 kg/ha/yr.

Limited data from surface runoff studies on turfgrass suggests that runoff is very low to nondetectable (Gross *et al.*, 1990; Harrison *et al.*, 1993; Linde *et al.*, 1995), but that runoff amount depends on soil characteristics and rainfall patterns. Linde *et al.* (1995) reported detectable runoff (> 0.6 mm/h) from five of 13 events on creeping bentgrass and perennial ryegrass plots with 9 to 11 percent slopes. Harrison *et al.* (1993) reported no detectable runoff from natural precipitation on turfgrass plots maintained as home lawns on 9 to 14 percent slopes. They were, however, able to force runoff with irrigation amounts approaching 152 mm/h. Unlike Harrison *et al.* (1993), Gross *et al.* (1990) recorded 18 runoff events ranging from 7 mm to 137 mm, with a median of 25 mm, over a two-year period.

Previous studies have addressed runoff volume and nutrient loss; however, these studies focused on small areas from plots up to individual greens or fairways (Kenna, 1995; Cohen *et al.*, 1999). Studies on small scales are valuable, but they may not represent the diversity and connectivity associated with a complete turfgrass system. Cohen *et al.* (1999) emphasizes the need for field-scale water quality studies on golf courses. The objective of the work reported in this study is to quantify the impact of a typical managed municipal turfgrass environment on surface water nutrient concentrations and loadings. The results may be helpful in determining concentrations and loadings from turfgrass systems to be incorporated into urban total maximum daily load (TMDL) projects. This study represents a unique turfgrass monitoring program that will allow quantification of the water quality loadings of turfgrass environments.

METHODS AND MATERIALS

Experimental Site

A section of Morris Williams Municipal Golf Course in Austin, Texas, managed by the City of Austin Parks and Recreation Department (PARD), served as the study site for this project. This site was constructed in 1963 and is located just south of Robert Mueller Municipal Airport between Manor Road and MLK Boulevard (Figure 1). The selected section of the course is ideal for studying surface water, as the section has only one inlet and one outlet for runoff, thus the boundary conditions are easily monitored. The topography is such that the contributing area (29.04 ha) contains 10 greens (0.73 ha), seven fairways (8.23 ha), and seven tees (0.30 ha). The managed areas (greens, fairways, and tees) represent 32 percent of the total area. The contributing area also contains approximately 6.5 ha of reduced-managed rough, with the remainder comprised of unmanaged trees and shrubs. Cohen *et al.* (1999) express the need for the examination of adjacent land uses in golf course studies. This experimental site allows upstream nutrient contributions to be measured, so that the turfgrass system contribution can be determined.

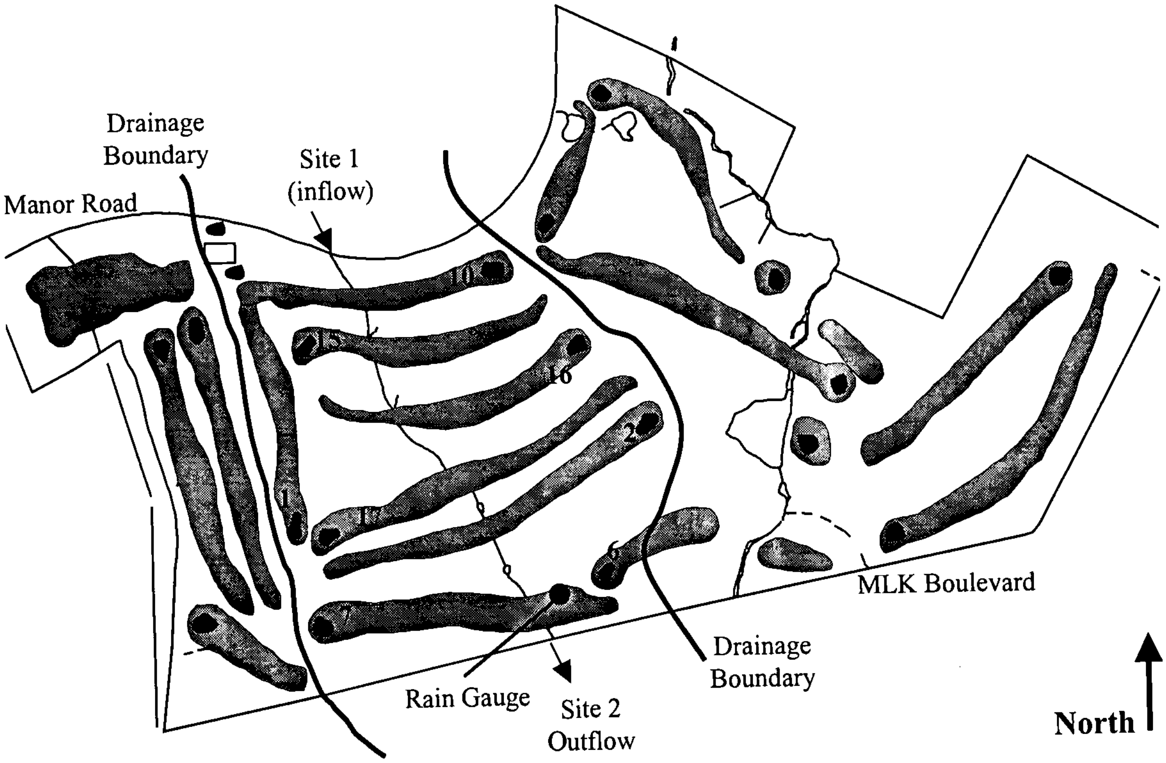

Figure 1. Layout of Study Area at Morris Williams Golf Course.

The 30-year normal precipitation for Austin, Texas, is 810 mm (NOAA, 1993). Normal daily temperatures range from a minimum of 4.2°C in January to a maximum of 35°C in August. Austin has an average of 273 growing season days per year.

Soils. Soils on Morris Williams have been subjected to considerable disturbance and redistribution caused by municipal airport construction projects. As a result, the soil mapping units (Table 1) were observed as a patchwork of soils formed in alluvium, clayey bedrock, and marl bedrock. The Travis (fine, mixed, thermic Ultic Paleustalfs) mapping unit occupies the largest area on the site. Travis soils are not as deep as the other soils in this location. Scattered areas of silty clays consisting primarily of Lewisville (fine-silty, mixed, thermic Udic Calciustolls) and Altoga (fine-silty, carbonatic, thermic Udic Ustochrepts) soils are located on the western and eastern portion of the site. Travis, Lewisville, and Altoga soils all have low to moderate potential for runoff. However, the clayey Houston Black (fine, montmorillonitic, thermic Udic Haplusterts) and Ferris (fine, montmorillonitic, thermic chromic Udic Haplusterts) soils have a high potential for runoff as well as for preferential flow. These soils are located in the center of the course. Frio (fine, montmorillonitic, thermic Cumulic Haplustolls) soils are found in the floodplain surrounding the branch of Tannehill Creek. Frio soils have a moderate rating for surface runoff.

Course Management. During the study period, Morris Williams Golf Course was managed at a moderately intense level, typical of most municipal courses in the U.S. Fairways and greens were seeded with bermudagrass (*Cynodon dactylon* L. Pers.). Greens were overseeded in late fall with perennial ryegrass (*Lolium perenne* L.). The golf course is irrigated with a mixture of potable water from the city and water pumped from a tributary branch of Tannehill Creek. Irrigation is applied on an "as needed" basis determined by course personnel in an attempt to match evapotranspiration losses. Based on golf course records, estimated average annual irrigation amounts for 1998 and 1999 were 890 mm (35 in) for the fairways and 1220 mm (48 in) for the greens and tees. Irrigation is limited to 13 mm (1/2 in) and 9 mm (1/3 in) per application for fairways and greens, respectively. The roughs and unmanaged areas were not irrigated. Based on target irrigation amounts, nutrient concentrations in the irrigation water (Table 2) averaged over the entire study area resulted in application amounts of 1.0 kg/ha NO_3+NO_2-N, 0.6 kg/ha NH_4-N, and 0.2 kg/ha PO_4-P. Assuming 0.8 mg/L NO_3-N concentration in precipitation, 5.9 kg/ha NO_3-N was applied over the study area for the 13-month period.

Table 1. Soil Mapping Units at Morris Williams Golf Course.

Soil Mapping Unit	Dominant Texture	NRCS Hydrologic Soil Group	Extent of Unit (ha)	Percent of Total Area*
Altoga (2 to 8 % slope)	Silty clay	C	3.1	4.0
Ferris (8 to 20% slope)	Clay	D	2.9	3.7
Frio (channeled)	Silt clay loam	B	3.0	3.9
Frio (frequently flooded)	Silty clay loam	B	1.3	1.7
Houston Black + Urban (1 to 3% slope)	Gravelly clay	D	8.0	10.4
Lewisville (0 to 2% slope)	Silty clay loam to clay loam	B	17.7	22.9
Travis + Urban (1 to 8% slope)	Gravelly loamy sand over sandy clay/ sandy clay loam	C	40.2	52.2

*1.2 percent of the total area is occupied by perennial streams, ponds, and the irrigation basin.

TABLE 2. Measured Nutrient Concentrations (n = 44) From the Irrigation Basin.

Statistic	NO_3+NO_2-N	NH_4-N	PO_4-P
Mean (mg/L)	0.35	0.19	0.07
Median (mg/L)	0.34	0.13	0.06
Maximum (mg/L)	0.86	0.98	0.18

Fertilizer was applied by broadcast and boom sprayer techniques throughout the year as a combination of organic, bio-stimulant, slow release, and fast release formulations (Table 3). Reported commercial fertilizer applications (Table 3) indicate nitrogen rates on greens of 541 kg/ha (11 lbs per 1000 ft^2), 270 kg/ha (5.5 lbs per 1000 ft^2) on tees, and 216 kg/ha (4.4 lbs per 1000 ft^2) on fairways. Averaged over the 29.04 ha study area for the 13-month study period, nitrogen application rates were 88.5 kg/ha while phosphorus rates were 2.3 kg/ha. No efforts were made to estimate mineralization amounts of grass clippings dropped back on the course after mowing. During the study period, the course was subjected to several turfgrass renovation projects. Therefore, a higher percentage of soluble nitrogen formulations were used compared to typical maintenance. Pesticide applications were made based on typical applications for this study region. Greens were mowed daily during the growing season while fairways were mowed every other day. During the period when greens were overseeded with ryegrass, they were mowed every two days.

Data Collection

Quantification of water quantity and quality from watershed turfgrass systems is often difficult because of the temporal and spatial variability associated with a natural system and, in many cases, the lack of true control volumes to determine boundary conditions. Surface water quantity and quality data were collected from March 20, 1998, to April 30, 1999. Flow depth measurements were continuously recorded in 15-minute intervals for the period of study. A rating curve along with the flow depth measurements were used to estimate mass fluxes for each event. Storm flow and baseflow were sampled for NO_3+NO_2-N, NH_4-N, and PO_4-P. Precipitation was collected using a tipping bucket rain gauge located in the course. Rainfall was assumed to be uniform over the study area.

Hydrology. The drainage way, which transects the center of the course (Figure 1), conducts surface runoff from the airport onto the course at Site 1, located near Manor Road at the tenth fairway, and exits the course at Site 2, located near MLK Boulevard at the seventh fairway. A small stream (approximate top width of 2 m), with several grassed waterways (fairways and roughs) and culverts, runs through the study section. The stream eventually drains into Tannehill Branch and the Colorado River. Since the drainage way receives considerable runoff input from impermeable areas at the airport, runoff tends to peak rapidly.

TABLE 3. Reported Commercial Fertilizer Applications for Morris Williams Golf Course.

Date	Source	Amount (kg/ha)	Actual N (kg/ha)	Actual P (kg/ha)
Greens (0.73 ha)				
March 2, 1998	19-0-17	186.4	35.4	–
March 9, 1998	10-0-20	179.7	18.0	–
March 11, 1998	19-0-17	211.2	40.1	–
March 25, 1998	Organic (4-2-2)	377.4	15.1	7.5
April 2, 1998	15-0-15	130.3	19.5	–
April 21, 1998	15-0-15	314.5	47.2	–
May 4, 1998	22-0-12	179.7	39.5	–
June 3, 1998	29-3-8	137.0	30.1	4.1
August 12, 1998	19-0-17	219.0	41.6	–
August 19, 1998	29-3-8	101.1	29.3	3.0
November 4, 1998	19-28-5	142.6	27.1	39.9
December 14, 1998	19-0-17	164.0	31.1	–
December 31, 1998	31-3-10	112.3	34.8	3.4
January 7, 1999	23-3-5	97.7	22.5	2.9
January 21, 1999	20-0-17	140.2	28.0	–
February 25, 1999	20-0-17	140.4	28.1	–
March 9, 1999	19-4-6	202.2	38.4	8.1
March 24, 1999	Organic (4-2-2)	377.4	15.1	7.5
Total			**540.9**	**76.4**
Tees (0.3 ha)				
March 2, 1998	19-0-17	128.9	24.5	–
April 2, 1998	19-0-17	128.9	24.5	–
May 5, 1998	21-0-0	116.7	24.5	–
June 15, 1998	21-0-0	116.7	24.5	–
July 13, 1998	21-0-0	116.7	24.5	–
September 2, 1998	19-0-17	128.9	49.0	–
October 12, 1998	19-28-5	128.9	24.5	36.1
November 4, 1998	19-0-17	128.9	24.5	–
December 14, 1998	19-0-17	128.9	24.5	–
February 26, 1999	19-0-17	128.9	24.5	–
Total			**269.5**	**36.1**
Fairways (8.23 ha)				
February 17, 1998	10-0-20	96.5	9.7	–
May 5, 1998	21-0-0	249.6	52.4	–
June 15, 1998	21-0-0	249.6	52.4	–
July 13, 1998	21-0-0	249.6	52.4	–
April 4, 1999	20-0-20	245.1	49.0	–
Total			**215.9**	**-**
Roughs (6.50 ha)				
April 4, 1999	20-0-20	245.1	49.0	–
Total			**49.0**	

Site 1 is characterized by two entrance culverts (draining the airport and Manor Road). Each culvert was equipped with an ISCO 4150 area velocity flow logger. (Trade names are included for the benefit of the reader and do not imply endorsement by USDA.) Inflow to the course was measured by relating the stream depth collected every 15 minutes to area-velocity measurements for the two entrance culverts. Likewise, Site 2 was characterized by a box culvert that drains water from the course under MLK Boulevard. Similarly, an ISCO 4150 area velocity meter and crest stage gauges were installed to measure the discharge leaving the course. Stream stage (measured continuously at 15-minute intervals) was related to area-velocity measurements in the box culvert to arrive at discharge values. Since both sites are characterized by true control volumes (culverts), the measured flow can be reported with considerable confidence.

Water Quality. Surface water samples (storm flow and baseflow) were collected throughout the study period. Two ISCO 6700 automatic collection systems were installed on the course at Sites 1 and 2. Time-weighted composite samples with six samples per bottle were collected automatically during storm runoff events to evaluate storm nutrient flux. The first 24 samples were taken at five-minute intervals, the next 48 samples at 15-minute intervals, the next 48 samples at 30-minute intervals and the last 24 samples at 60-minute intervals. Samples were collected in mid-stream and a well, mixed condition was assumed. Grab samples were also collected approximately once per week to evaluate baseflow conditions. Following rainfall events, samples were acidified and iced for transport to the laboratory for analysis. All samples were handled and analyzed according to an Environmental Protection Agency (EPA) and a Texas Natural Resource Conservation Commission (TNRCC) approved quality assurance procedure. All samples were analyzed colorimetrically for NO_3+NO_2-N, NH_4-N, and PO_4-P concentrations using a Technicon Autoanalyzer IIC and methods published by Technicon Industrial Systems (1973a, 1973b, 1976). The samples were unfiltered and nondigested. Sediment leaving the course was negligible.

Quality Assurance. When collecting data in natural environments, it must be understood that even with sophisticated measuring devices and instruments, the measure of a real world situation still remains, at best, an estimate. However, it should be noted that all measures were taken to confine the errors associated with the measurements to those associated with the instruments used in the field and laboratory. Laboratory quality assurance analyses resulted in blank concentrations less than the published Technicon procedure detection limits. Replicates (precision limits) were all within 0 to 5 percent, and measured laboratory spikes (accuracy limits) were all within 0 to 8 percent of known concentrations; however, most were well below 5 and 8 percent, respectively.

Statistical Analysis

Time-weighted concentrations for each constituent were evaluated using Minitab® (1998) statistical software. Normality was tested using the Anderson-Darling statistic ($\alpha < 0.05$). If the data were normally distributed, means were evaluated with a paired t-test. If the data were not normally distributed, median concentrations were compared with the Mann-Whitney nonparametric test.

RESULTS AND DISCUSSION

Hydrology

Precipitation for the 13-month period of study totaled 738 mm. During the study period, 22 events with measurable runoff occurred (Table 4). These 22 events accounted for 98 percent (722 mm) of the total measured precipitation. Maximum measured one-hour intensities ranged from 2.8 mm/hr to 64 mm/hr (Table 4). Baseflow from the course was approximately 1.5 mm per day. Baseflow was primarily return flow fed by irrigation and routed by french drains throughout the course.

Surface runoff from the 22 events was estimated at 98 mm, or 13 percent of precipitation (Table 4), which is comparable to measured no-till agricultural runoff losses from similar soils (King *et al.*, 1996). Runoff was impacted by the well-watered condition of the course and clayey surface soils. Antecedent soil moisture on the greens and fairways rarely if ever was allowed to drop below 85 percent of available water capacity. The larger Q/P ratios (Table 4) on some of the small events are indicative of the difficulty involved in establishing stage-discharge relationships for low flows in a natural environment, even when true control volumes exists. In these culverts at low flows, small debris dams can form. If the flow does not become large enough to flush out the debris, stage readings at very low flows may be influenced.

The variation associated with the runoff measurements can be quantified by comparing the event discharges estimated with the continuous 15-minute

TABLE 4. Precipitation Characteristics and Runoff for Storm Events.

Storm Date	Precipitation (mm)	Maximum 15-Minute Precipitation (mm)	Maximum One-Hour Precipitation (mm)	Measured Golf Course Runoff* (mm)	Runoff-Precipitation Ratio (Q/P)
March 30, 1998	12.7	4.3	5.9	0.3	0.02
April 8, 1998	7.1	3.8	6.9	1.2	0.17
April 26, 1998	4.4	3.3	3.6	1.3	0.30
May 27, 1998	11.7	6.9	9.7	2.3	0.20
June 11, 1998	13.9	6.4	11.4	2.7	0.19
June 28-29, 1998	9.1	1.5	3.8	1.7	0.19
July 3-4, 1998	20.3	7.1	8.6	6.5	0.32
August 6, 1998	5.1	1.0	2.8	0.2	0.04
August 17-18, 1998	6.6	3.1	6.4	0.6	0.09
August 23, 1998	16.7	3.6	4.1	0.8	0.05
September 10-12, 1998	56.3	5.6	10.7	1.6	0.03
September 15-16, 1998	79.5	12.7	21.1	6.6	0.08
October 5-6, 19989	70.1	20.6	35.9	3.0	0.04
October 17-21, 1998	187	25.7	63.5	41	0.22
November 1, 1998	43.2	15.8	35.8	1.1	0.03
November 12-15, 1998	44.8	3.6	5.6	2.6	0.06
December 10-11, 1998	25.8	2.3	4.3	3.8	0.15
March 8, 1999	4.3	2.3	4.4	1.0	0.23
March 12-13, 1999	37.6	7.6	15.5	6.0	0.16
March 18-19, 1999	38.1	9.9	21.1	9.7	0.25
March 27-28, 1999	15.0	4.3	9.2	1.2	0.08
April 25-26, 1999	12.5	2.5	4.1	2.4	0.19
Total	**722**			**98**	

*Measured runoff was calculated as the difference between Site 1 and Site 2.

flow to the flow measured with the variable sampling scheme (5-, 15-, 30-, and 60-minute flows). If the assumption is made that the 15-minute flows are true, then the absolute difference can be quantified as the difference between the two values. This results in a range of absolute differences of 0.01 mm to 3.84 mm, with a median of 0.66 mm. The maximum absolute difference corresponds to only 3.9 percent of the total measured discharge for the 13-month period. These findings indicate that either method of determining discharges is appropriate.

Surface Water Quality

Storm Flow Analysis. A complete set of storm flow samples for each site was collected for 18 of the 22 runoff events during the 13-month study period. Equipment failure prevented complete sample collection for four events at Site 1 and two events at Site 2. Based on collected data (Table 5), storm flow from the system contributed statistically significant ($p < 0.05$) increases in median NO_3+NO_2-N concentrations (+0.30 mg/L), decreases in NH_4-N concentrations(-0.05 mg/L), and no change in PO_4-P concentrations. Storm flow concentrations of NO_2+NO_3-N, NH_4-N, and PO_4-P exiting the course rarely exceeded TNRCC (1998) nutrient screening levels (Table 6).

To calculate estimates of storm loads, the complete data set for 18 storms and concentration estimates for the other four storms were used. Concentrations for the four events that were not measured were assumed equivalent to the median concentrations using every measured sample per site. The use of median concentrations was validated by a comparison to a load versus discharge relationship with similar results. The nutrient load for each of the 18 storms was

TABLE 5. Statistical Analysis* of Nutrient Concentrations (mg/L) in Storm Flow and Baseflow.

	NO_3+NO_2-N		NH_4-N		PO_4-P	
	Site 1	**Site 2**	**Site 1**	**Site 2**	**Site 1**	**Site 2**
Storm Flow Concentrations (mg/L) (n = 190 for Site 1 and n = 249 for Site 2)						
25th Percentile	0.08	0.29	0.04	0.00	0.07	0.10
Median	0.20a	0.50b	0.08a	0.03b	0.13a	0.13a
75th Percentile	0.34	0.84	0.15	0.07	0.20	0.18
Maximum	1.24	3.52	4.04	1.74	0.90	0.43
Baseflow Concentrations (mg/L) (n = 39)						
25th Percentile	0.42	0.93	0.11	0.01	0.08	0.08
Median	0.53a	1.39b	0.16a	0.02b	0.10a	0.11a
75th Percentile	0.64	1.82	0.22	0.06	0.15	0.12
Maximum	0.91	2.35	0.69	0.17	0.37	0.19

*Medians were evaluated with the Mann-Whitney nonparametric test. Medians for each constituent followed by the same letter are not significantly different ($p < 0.05$).

TABLE 6. Number of Samples Exceeding the TNRCC Screening Level Per Constituent for All Storm Flow and Baseflow Samples.

	Site 1			Site 2		
	NO_3+NO_2-N	NH_4-N	PO_4-P	NO_3+NO_2-N	NH_4-N	PO_4-P
Screening Level (mg/L)	3.1	0.3	1.4	3.1	0.3	1.4
Storm Flow						
No. Exceeded/Total	0/190	27/190	0/190	4/249	8/249	0/249
Percent (%)	0	14	0	2	3	0
Rating Level*	NC	PC	NC	NC	NC	NC
Baseflow						
No. Exceeded/Total	0/39	6/39	11/39	0/39	0/39	3/39
Percent (%)	0	15	28	0	0	8
Rating Level	NC	PC	C	NC	NC	NC

*No concern (NC), potential concern (PC), concern (C).

calculated as the sum of the concentration for each bottle multiplied by the time-weighted flow during collection of that bottle. Nutrient loads for the four storms without complete sets of samples were estimated as the median nutrient concentration (from the complete storm samples at that site) multiplied by the storm's flow volume (Table 4). The estimated storm flow contributions for the study period due to course runoff, $\Sigma(Q_2c_2 - Q_1c_1)$, were 2.3 kg/ha NO_3+NO_2-N and 0.33 kg/ha PO_4-P (Table 7). Storm flow accounted for the attenuation of 0.12 kg/ha of NH_4-N. These storm flow amounts represent approximately 2.6 percent of commercial applied N and 14.3 percent of applied P over the contributing area for the same period (Table 3). This apparent high percentage of applied-P losses in storm flow is surprising considering the relative immobility of P in turfgrass soils (Walker and Branham, 1992). Current background levels of Olsen extractable P in the soil (0-150 mm) ranged from 9 mg/kg in the roughs to 44.5 mg/kg in the greens. Although the current management strategy is to use a low level phosphorus fertilizer (Table 3), the residual phosphorus in soil from previous heavy applications during course establishment is still available for low level losses in storm flow. Similar findings have been reported from agricultural land use areas (Stamm *et al.*, 1998; Sims *et al.*, 1998; Gburek and Sharpley, 1998). This may account for the higher

TABLE 7. Estimated Nutrient Loads in Storm Flow for 22 Events With Measurable Runoff.

	NO_3+NO_2-N (kg)		NH_4-N (kg)		PO_4-P (kg)	
Storm Date	**Site 1**	**Site 2**	**Site 1**	**Site 2**	**Site 1**	**Site 2**
March 30, 1998	0.4	0.7	0.0	0.0	0.0	0.0
April 8, 1998	0.2	0.5[1]	0.0	0.01	0.0	0.1[1]
April 26-27, 1998	0.1	0.4	0.0	0.0	0.1	0.1
May 27, 1998	0.3	1.0	1.1	1.4	0.1	0.2
June 11, 1998	0.3	0.5	0.0	0.1	0.0	0.1
June 28-29, 1998	0.1	0.5	0.1	0.1	0.1	0.2
July 3-4, 1998	0.1	0.7	0.1	0.1	0.2	0.3
August 6, 1998	0.0	0.1	0.0	0.0	0.0	0.0
August 17-18, 1998	0.1	0.2	0.1	0.0	0.0	0.0
August 23, 1998	0.0	0.2	0.0	0.0	0.1	0.1
September 10-12, 1998	1.4[2]	3.3	0.5[2]	0.0	0.9[2]	1.2
September 15-16, 1998	3.6[2]	8.7	1.4[2]	0.4	2.4[2]	3.9
October 5-6, 19989	3.9[3]	19	1.5[3]	1.7	2.5[3]	7.2
October 17-21, 1998	15[3]	46[3]	5.48[3]	2.58[3]	128[3]	12[3]
November 1, 1998	2.8	5.3	1.5	1.4	2.7	2.9
November 12-15, 1998	0.4	2.6	1.6	0.9	1.5	2.2
December 10-11, 1998	0.9	2.3	0.3	0.3	0.3	0.7
March 8, 1999	0.1	0.4	0.0	0.0	0.0	0.0
March 12-13, 1999	0.4	1.7	0.2	0.5	0.1	0.4
March 18-19, 1999	1.9	4.1	0.8	1.7	0.8	1.8
March 27-28, 1999	0.5	1.0	0.1	0.2	0.1	0.1
April 25-26, 1999	0.0	0.1	0.1	0.1	0.1	0.2
Total (kg)	**32.5**	**99.3**	**14.8**	**11.4**	**24.0**	**33.7**
Study Area Contribution (kg/ha)	**2.3**		**-0.12**		**0.33**	

[1] Estimated from median concentration (mg/L) values for Site 2 (0.497 for NO_3-N, 0.029 for NH_4-N, and 0.135 for PO_4-P) from storms where PO_4-P) from storms where complete data was available.

[2] Estimated from median concentration (mg/L) values for Site 1 (0.200 for NO_3-N, 0.079 for NH_4-N, and 0.133 for PO_4-P) from storms where complete data was available

[3] Partial data from events was estimated using median concentration values previously noted.

percentage phosphorus losses compared to current application levels. The movement of residual soil phosphorus may be a result of both elevated surface runoff and subsurface lateral flow losses of phosphorus during and after storm flow events. Despite the relative immobility of phosphorus in turfgrass soils (Walker and Branham, 1992), the results of this study suggest that soils with high background levels of phosphorus may have the potential for low but significant contributions of phosphorus to surface water.

The nutrients recovered in the storm flow may be a result of excess application and the use of more soluble nitrogen compared to slow release nitrogen, but could also be a result of nutrients being suspended in the thatch layer and being transported through runoff. Once applied, the nutrients are usually watered in to about 2 mm (top of the thatch layer). When excess precipitation occurs, runoff migrates through the thatch layer. Since most of the fertilizers are of a soluble form, they are immediately available for transport. Similar findings have been reported by Torbert *et al.* (1999) on bermudagrass (*Cynodon dactylon* L. Pers.).

Baseflow Analysis. Based on grab sample data (Figure 2), the golf course contributes a significant increase in median concentration of NO_3+NO_2-N (+0.86 mg/L) to baseflow exiting the course (Table 5).

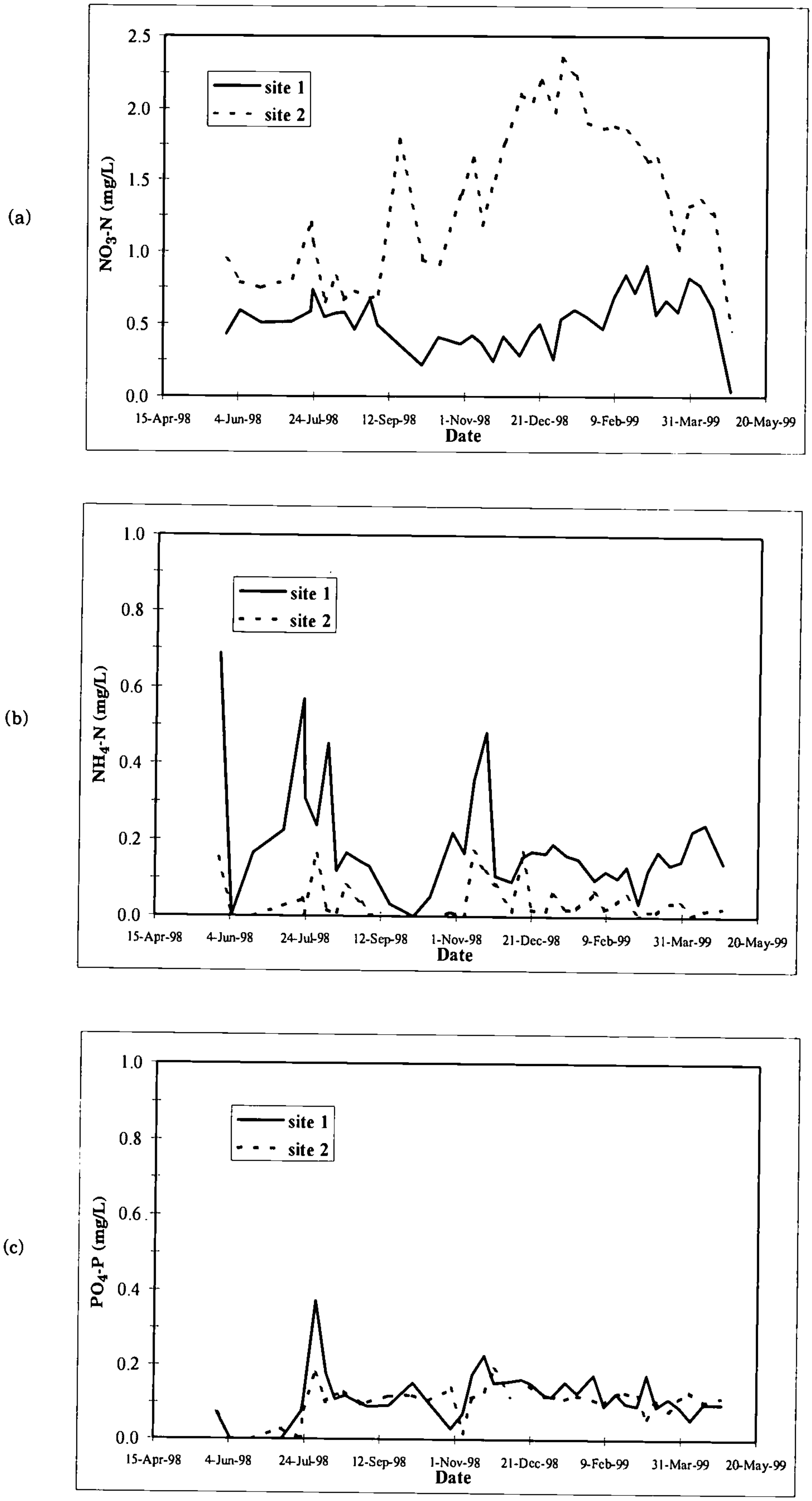

Figure 2. Grab Sample Concentration Data for (a) NO_3+NO_2-N, (b) NH_4-N, and (c) PO_4-P, for Period of Record.

NH_4-N concentrations were reduced in baseflow (-0.14 mg/L), and the course had no significant effect on PO_4-P concentrations in baseflow (Table 5). These results were similar and consistent with storm flow concentration contributions. Seasonal trends of NO_3+NO_2-N in the baseflow were observed. NO_3+NO_2-N levels in baseflow at the downstream site were consistently higher than at the upstream site, with differences being greater from fall to spring which is the period of turfgrass dormancy. In contrast, NH_4-N levels were consistently higher at the upstream site, and no seasonal patterns were observed. PO_4-P concentrations were similar at both sites and steady throughout the year. Baseflow concentrations of NO_2+NO_3-N, NH_4-N, and PO_4-P exiting the course rarely exceeded TNRCC (1998) nutrient screening levels (Table 6).

The system's nutrient contribution in baseflow was estimated from the difference in median concentrations from each site and the baseflow volume for the period of study. Removing the days when runoff was present (baseflow was not separated from storm flow) results in 367 total days for baseflow calculations. By using an estimated 1.5 mm per day baseflow over 367 days and median concentrations at each site (Table 5), NO_3+NO_2-N loss in the baseflow was calculated as 4.7 kg/ha. PO_4-P losses were estimated at 0.06 kg/ha, while 0.8 kg/ha of NH_4-N were attenuated in baseflow by volatilization or transformation to NO_3-N.

SUMMARY AND CONCLUSIONS

Hydrologic and water quality data were collected on a watershed scale turfgrass environment for 13-months. Measured concentration data suggests a positive contribution of nutrients from the turfgrass system, although quite small. Based on concentration data, this turfgrass system increased NO_3+NO_2-N concentrations and loads to stream flow exiting the course. Combined stream flow and baseflow from the study section added 7.0 kg/ha NO_3+NO_2-N (7.9 percent of N applied) to the stream. PO_4-P concentrations exiting the course were not significantly greater than inflow concentrations; however, the PO_4-P load (0.33 kg/ha) recovered in the storm flow was considerably large compared with applied phosphorus (14.3 percent of P applied) for the same time period. Storm flow from the course attenuated 0.12 kg/ha of NH_4-N, while baseflow through the course attenuated 0.8 kg/ha of NH_4-N by volatilization and/or transformation to NO_3-N.

Nutrient levels in baseflow and storm flow exiting the course were generally well below screening levels. This result indicates that under current management scenarios nutrient levels in stream flow exiting the course do not pose immediate threats to health of human or aquatic organisms. However, this study does indicate the potential for nutrients applied to golf courses to exit the course in stream flow, which may contribute to water quality degradation (such as algal blooms and low dissolved oxygen). The objectives were to quantify the quality and quantity of surface water leaving the turfgrass system, therefore surface – ground water interactions, preferential flow, and other flow dynamics were not differentiated in this study. However, based upon the findings it can be concluded that efforts should be undertaken that focus on the transport and flow dynamics of turfgrass systems. In addition, similar studies should also be initiated where management, soils, and climate vary from those in Austin, Texas. The findings reported within this manuscript may be used for application to TMDL projects with turfgrass systems having similar physical and geographical characteristics. The results also support the need for turf system managers to carefully manage nutrient inputs.

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