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Scientists from the USDA Agricultural Research Service and Spectrum Research, Inc. instrumented the Morris Williams Municipal Golf Course in Austin, TX to investigate the nutrient concentrations and loads that might be expected from typical management on municipal golf courses in a semi-arid climate. Surface and subsurface hydrology and nutrient concentrations were measured for a five-year period

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PURPOSE

The purpose of *USGA Turfgrass and Environmental Research Online* is to effectively communicate the results of research projects funded under USGA's Turfgrass and Environmental Research Program to all who can benefit from such knowledge. Since 1983, the USGA has funded more than 290 projects at a cost of $25 million. The private, non-profit research program provides funding opportunities to university faculty interested in working on environmental and turf management problems affecting golf courses. The outstanding playing conditions of today's golf courses are a direct result of ***using science to benefit golf***.

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Surface and Subsurface Nutrient Transport from a Golf Course Watershed

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SUMMARY

Scientists from the USDA Agricultural Research Service in Columbus, Ohio and Spectrum Research, Inc. instrumented the Morris Williams Municipal Golf Course in Austin, TX to investigate the nutrient concentrations and loads that might be expected from typical management on municipal golf courses in a semi-arid climate. Surface and subsurface hydrology and nutrient (NO_3-N, NH_4-N, and dissoloved reactive phosphorous, DRP) concentrations were measured for a 5-year period (April 1, 1998 to March 31, 2003). Findings include:

- Estimated storm flow contributions were 1.2 kg ha^{-1} yr^{-1} NO_3+NO_2-N, 0.23 kg ha^{-1} yr^{-1} of NH_4-N, and 0.51 kg ha^{-1} yr^{-1} DRP. These storm flow amounts represent approximately 3.3% of applied N and 6.3% of applied P over the contributing area for the same period.
- The golf course contributes a significant increase in median concentration of NO_3+NO_2-N (+0.46 mg L^{-1}) to baseflow exiting the course. NH_4-N concentrations were reduced in baseflow (-0.06 mg L^{-1}), and the course had no significant effect on DRP concentrations in baseflow.
- NO_3-N concentrations (1.27 mg L^{-1} at Site 3; 0.32 mg L^{-1} at Site 4) and load (2.7 kg ha^{-1}) transported through the subsurface drainage water were approximately 1/10th the concentration and load typically reported for tile drainage from row crop agriculture.
- A strong seasonal pattern was detected. NO_3-N was present in greater concentrations in the surface and subsurface drainage water during the winter months (periods of greater rainfall, turfgrass dormancy, and reduced microbial activity) when compared to the spring and summer months.
- DRP concentrations in the subsurface drainage water were greater than concentrations measured in tile drains from agriculture and could pose a potential threat of eutrophication to a surface water system.
- The timing of NO_3-N and DRP movement through subsurface drainage from golf course turf appeared to be dependent on climatic factors (temperature and precipitation) and turf management factors (magnitude and timing of applications).
- The magnitude of NO_3-N and DRP concentrations was dependent on the frequency and amount of fertility management practices. At the more intensively managed site, consistently higher NO_3-N and DRP concentrations were detected in the drainage water than were measured from the less intensively managed site.

Turf may be defined as the managed surface layer of soil, grass plants, and the plant's matted roots. The grassed areas of home lawns, roadsides, commercial property, golf courses, parks, schools, churches, cemeteries, airports, and sod farms all fit this definition of turf. In the U.S, there are an estimated 17 million hectares (50 million acres) of turf (27). The largest percentage of turf is found in home lawns, while an approximate 4 million turf hectares (10 million acres) are located on roadside right-of-ways (11). Only 3% of the turf in the U.S. is managed as golf courses. According to the National Golf Foundation, there are approximately 17,000 golf courses operating in the United States.

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Surface water samples (storm flow and baseflow) from Site 1 and Site 2 were collected throughout the study period using ISCO 6700 automatic collection systems installed on the course.

Environmentally sound management of golf course turf provides both public and private facilities with environmental, cultural, and economic benefits (4). Public demand is increasing for golf course managers to maintain high quality turf on golf courses but also to protect water and soil resources in the vicinity of these facilities (2, 4). The perception (22, 30, 32, 36, 38) and potential (3) for nutrients to be transported in surface water is well documented. Management of existing golf courses and construction of new facilities is often a "lightning rod" of environmental and water quality concern (2). Whether or not that concern is warranted is often debated because of limited information on water quality exiting golf courses. High-quality golf course watershed-scale data are needed (7) to adequately address the issue of nutrient fate and transport on managed turf. The objective of this research effort was to quantify nutrient transport in surface and subsurface drainage waters from a golf course watershed.

Nutrient Losses from Turf

Periodic nutrient applications are an integral and essential part of establishing and maintaining high quality turf (6). However, these applications increase the potential for nutrients to be transported off site in surface runoff or through subsurface drainage features. Runoff and nutrient loss research from turf has been conducted at the field (8, 10, 12, 24, 28) and to a lesser extent the watershed scale (19, 23, 25, 41, 46). Research on subsurface losses of nutrients has generally focused on leachate (17, 28, 31) rather than the amounts moving laterally and returning to surface flow.

The general conclusions of the small-scale studies indicate that with well-maintained turf the amount of runoff is small and the concentrations of nutrients in the surface runoff are well below any level of major concern. While studies on small scales are valuable, they may not represent the diversity and connectivity associated with a

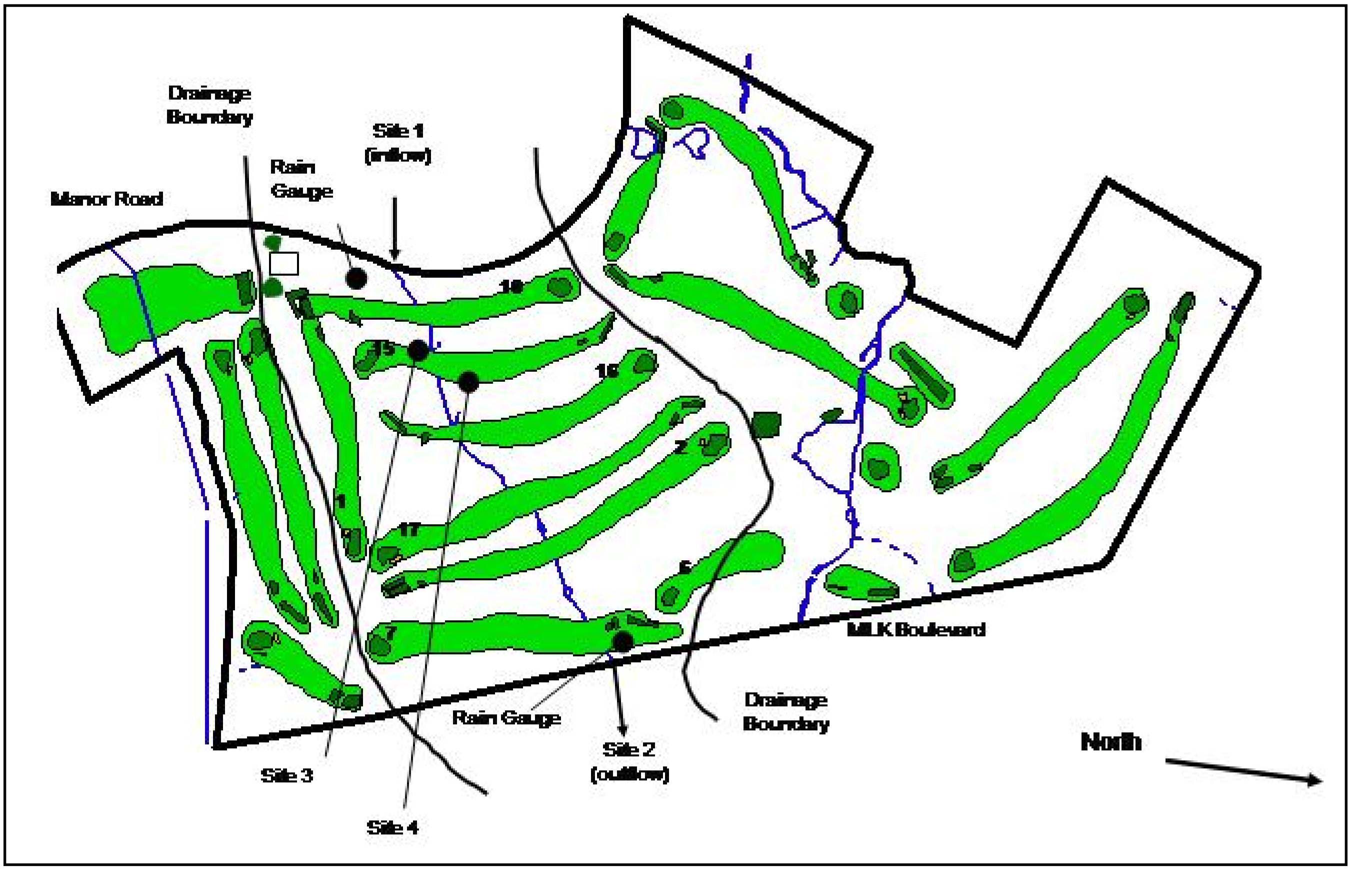

Figure 1. Layout of Morris Williams Municipal Golf Course in Austin, TX

watershed-scale system. The data collected from plot studies is also limited with regard to the temporal domain, many conducted for less than two years.

Watershed-scale golf course assessments indicate that concentrations (25, 41, 46) from water features on the golf courses are generally consistent with those reported in plot scale studies. Cohen et al. (7) reported that a survey of runoff on seventeen golf courses in the United States did not contain any cases of NO_3-N exceeding the drinking water standard of 10 mg L^{-1}. The median NO_3-N value recorded in that survey was 0.38 mg L^{-1}. Nutrient loading, however, is greater from the watershed scale systems when compared to plot studies.

Experimental Site

A section of Morris Williams Municipal Golf Course (MWMGC) in Austin, TX, managed by the City of Austin Parks and Recreation Department (PARD), served as the study site for this project. The study area (Figure 1) on MWMGC is characterized by a series of grassed waterways, culverts, and casual water detention areas that cross the center of the course. The topography is such that the contributing area (29 ha, 72 acres) contains 10 greens (0.73 ha, 1.8 acres), 7 fairways (8.23 ha, 20.3 acres) and 7 tees (0.30 ha, 0.74 acres). The managed areas (greens, fairways, and tees) represent 32% of the total area. The contributing area also contains approximately 6.5 ha (16 acres) of reduced-managed rough, with the remainder comprised of unmanaged trees and shrubs. Surface runoff was measured at the inlet and outlet of the study area. Subsurface drainage was measured from the 15th fairway, tee, and green (Figure 1).

The primary soils in the study area are Travis gravelly loamy sand over sandy clay (fine, mixed, thermic Ultic Paleustalfs) and Houston Black clay (fine, montmorillonitic, thermic Udic Haplusterts) (39). Travis soils are not as deep as the other soils in this location and have low to moderate potential for runoff. In contrast, the clayey Houston soils have a greater potential for runoff and preferential flow due to high shrink/swell characteristics.

The climate in Austin is characterized by long, hot summers and short, mild winters. Austin averages 273 growing-season days per year, generally lasting from mid-March to mid-November. Thunderstorms during the summer generate short intense rainfalls. Moisture in the form of frozen precipitation can occur but is generally negligible. The 30-year normal precipitation is 810 mm (32 inches, 29). Normal daily temperatures range from an average minimum of 4° C (39.2° F) in January to an average maximum of 35° C (95° F) in August.

Instrumentation, Data Collection, and Analysis

Surface and subsurface discharge and associated nutrient concentrations were recorded during a five-year period (April 1, 1998 - March 31, 2003) on MWMGC. Four sites (Figure 1) within the study area were instrumented with automated samples to collect stage and periodic water samples. The four sites were identified as: Site 1 (surface water entrance to the study area), Site 2 (surface water exit from the study area), Site 3 (subsurface drainage for the fairway (0.28 ha, 0.69 acres) south of the stream and green (0.05 ha, 1.012 acres) of hole number 15), and Site 4 (the fairway (0.72 ha, 1.78 acres) north of the stream and tee (0.02 ha, 0.05 acres) area of hole number 15). Site 1 is characterized by two entrance culverts (draining the old Austin airport and Manor Road).

Each culvert was equipped with an ISCO 4150 area-velocity flow meter. 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 Martin Luther King 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

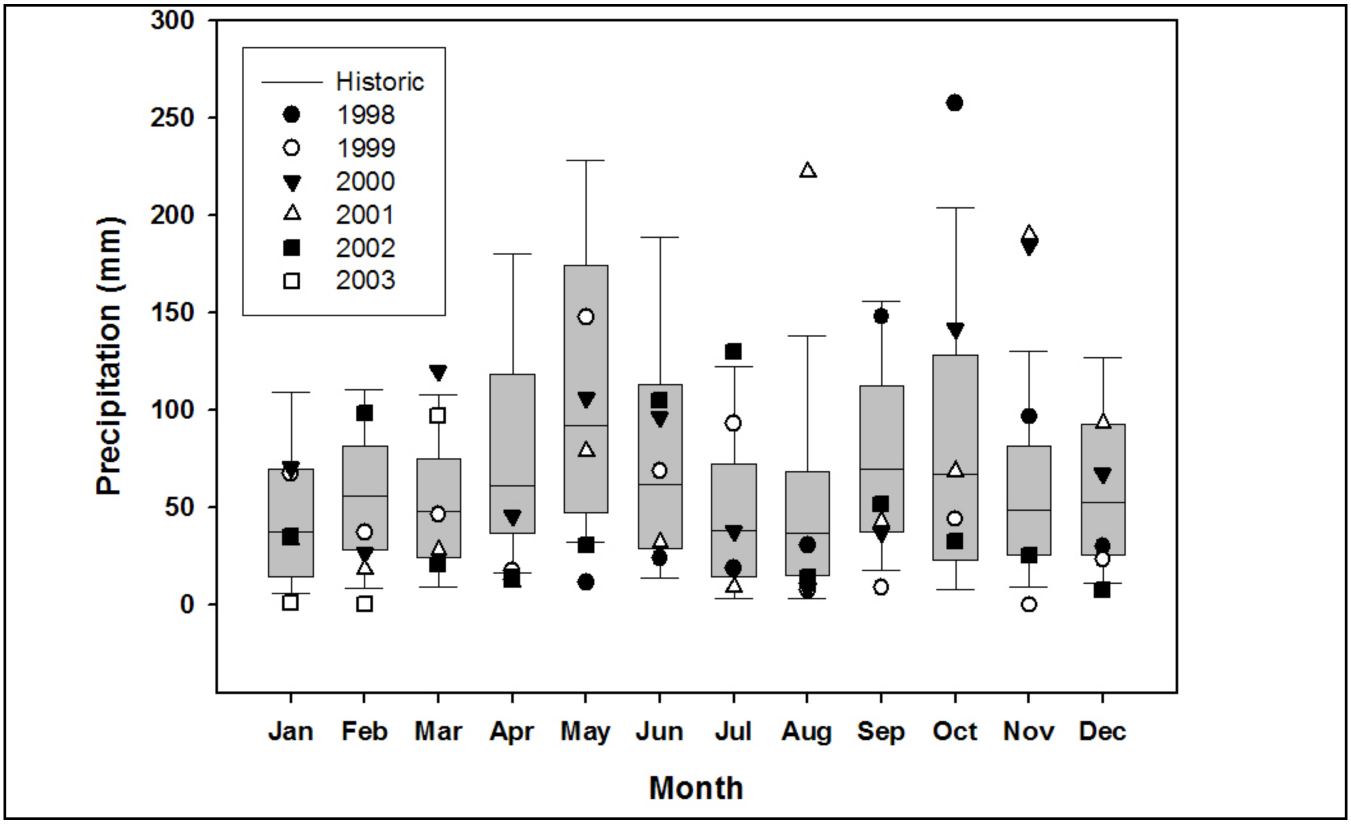

Figure 2. Historical (1900-2003) precipitation measured by National Weather Service for Austin, TX (boxes are bound by 25th and 75th percentile values; line in the box represents the median; whiskers represent the 10th and 90th percentiles) and study period (April 1, 1998 - March 31, 2003) measured precipitation at the experimental watershed site.

measurements in the box culvert to arrive at discharge values.

Surface water samples (storm flow and baseflow) from Site 1 and Site 2 were collected throughout the study period using ISCO 6700 automatic collection systems installed on the course. Time-weighted composite samples with six aliquots per sample were collected during storm runoff events to evaluate storm nutrient flux. The first 24 aliquots were taken at five-minute intervals, the next 48 aliquots at 15-minute intervals, the next 48 aliquots at 30-minute intervals, and the last 24 aliquots at 60-minute intervals. Samples were collected in midstream and a well-mixed condition was assumed. Grab samples were also collected approximately weekly to evaluate baseflow conditions.

Subsurface drainage was measured from French drains located on the 15th hole. The French drains were 0.6 meters (24 inches) deep and 0.3 m (12 inches) wide. The fill material was pea gravel overlaid by approximately 0.15 m (6 inch) wide strip of sod. Nutrient concentrations in the drainage water from the two sites were measured daily from April, 1999 to March, 2003 using automated samplers programmed to collect one sample every 24-hours. Quantifying subsurface flow from the French drains at the sampling sites was accomplished by forcing the drainage water through a V-notch weir. Water level above the bottom of the V-notch (water quantity) was recorded at 15-minute intervals for a period of 13-months at Site 3 and two years at Site 4 using ISCO 730 bubbler module technology. Bubbler module failure and cost for replacement prohibited a longer period of discharge sampling.

All samples were analyzed colorimetrically for NO_3+NO_2-N (hereafter referred to as NO_3-N), NH_4-N, and PO_4-P (hereafter referred to as DRP) concentrations using a Technicon Autoanalyzer IIC and methods published by Technicon Industrial Systems (42, 43, 44). The samples were unfiltered and non-digested. Sediment in the collected samples was negligible.

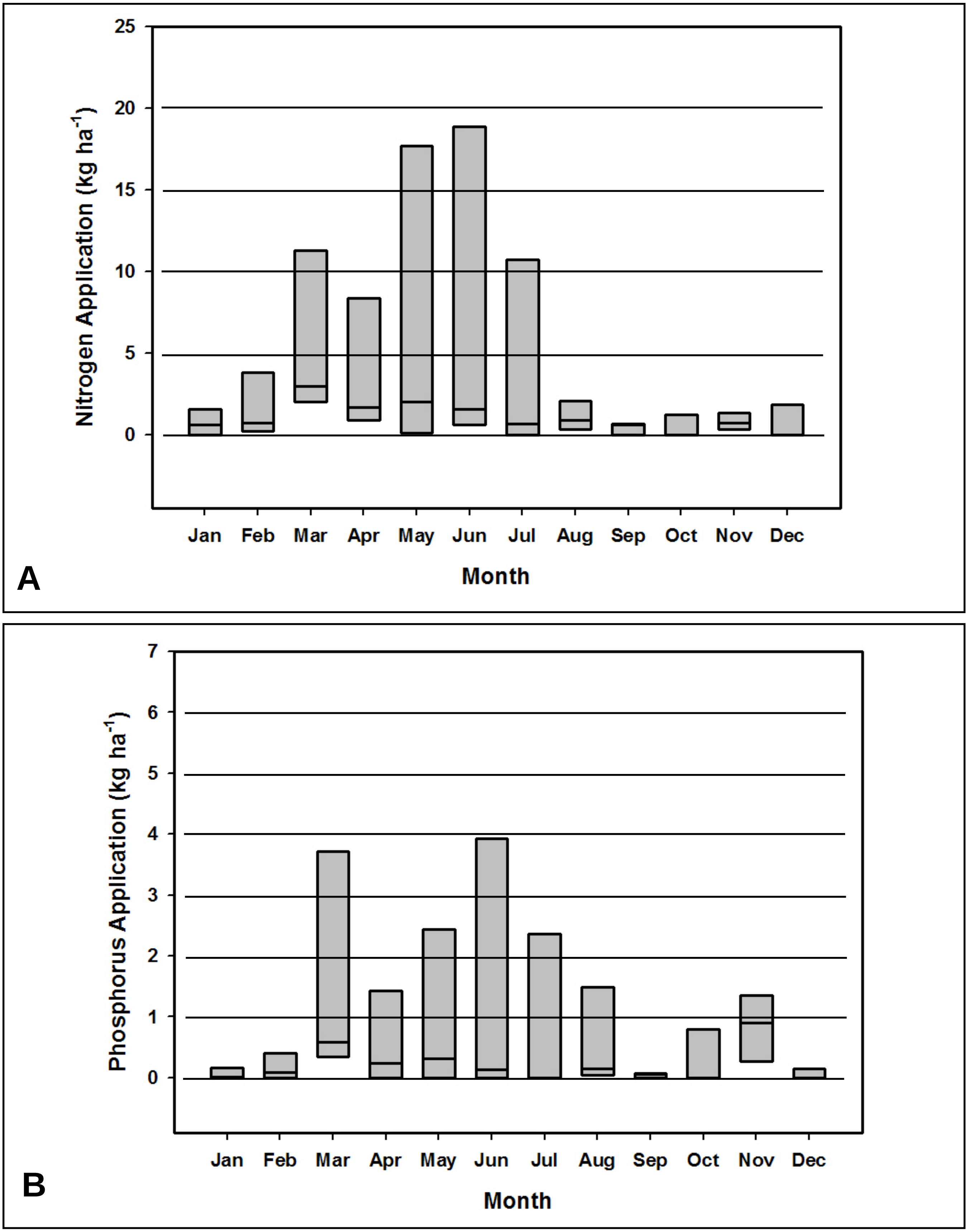

Figure 3. Variation of nitrogen (A) and phosphorus (B) fertilizer application at Morris Williams Municipal Golf Course during the study period. Fertilizer application data was totaled by month and averaged over the study area. Gray bars represent 25th and 75th percentiles, line represents the median of the data points in each month.

	Storm Flow Concentrations (mg L^{-1})					
	NO_3+NO_2-N		NH_4-N		PO_4-P	
	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
Mean	0.30	0.44	0.10	0.09	0.12	0.15
Median	0.23a	0.35b	0.05a	0.04b	0.10a	0.13b
Maximum	2.25	3.52	4.04	3.23	0.90	0.99
	Baseflow Concentrations (mg L^{-1})					
	NO_3+NO_2-N		NH_4-N		PO_4-P	
	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
Mean	0.30	0.79	0.10	0.03	0.11	0.10
Median	0.27a	0.73b	0.08a	0.02b	0.10a	0.10a
Maximum	1.84	2.35	0.69	0.17	0.37	0.27

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

Table 1. Statistical analysis† of nutrient concentrations (mg L-1) in storm flow and baseflow for 5-year period of record (April 1, 1998 to March 31, 2003). (Storm flow samples: n = 1050 for site 1,inflow; n = 1063 for site 2, outflow. Baseflow samples: n = 239).

Inputs

Precipitation was recorded with tipping-bucket rain gauges located at the inflow (Site 1) and outflow (Site 2) of the course (Figure 1). Monthly precipitation during the study period varied above and below the normal amounts (Figure 2). Annual precipitation during the five-year period ranged from 562 mm (22.1 inches) to 943 mm (37.1 inches). The golf course was irrigated with a mixture of potable water from the city and water pumped from an onsite reservoir. Irrigation was applied on an "as needed" basis, determined by course personnel, to replace evapotranspiration losses. Based on golf course records, estimated average annual irrigation amounts were 890 mm (35 in) for the fairways and 1220 mm (48 in) for the greens and tees. Irrigation was limited to 13 mm (1/2 in) on the fairways and 9 mm (1/3 in) on the greens per application. The roughs and unmanaged areas were not irrigated.

During the study period, management practices were typical of municipal courses in the southern U.S. Fairways and greens were seeded with a hybrid bermudagrass cultivar. Greens were overseeded in late fall with perennial ryegrass (*Lolium perenne* L.). Fertilizer was applied by both dry broadcast and spray techniques throughout the year (Figure 3) as a combination of organic, bio-stimulant, slow release, and fast release formulations. Annual average commercial fertilizer application rates for greens, fairways, and tees were determined from course records. Aerial weighted average annual N application mass for the study area (29.04 ha, 71.7 acres) was 36.3 kg ha^{-1}(40.8 lb $acre^{-1}$), while P applications totaled 8.1 kg ha^{-1} (7.2 lb $acre^{-1}$). No efforts were made to quantify the mass or decomposition of grass clippings dropped back on the course after mowing.

NO_3-N, NH_4-N, and DRP in Surface Flow

A complete set of storm flow samples for each site was collected for 109 of the 116 runoff

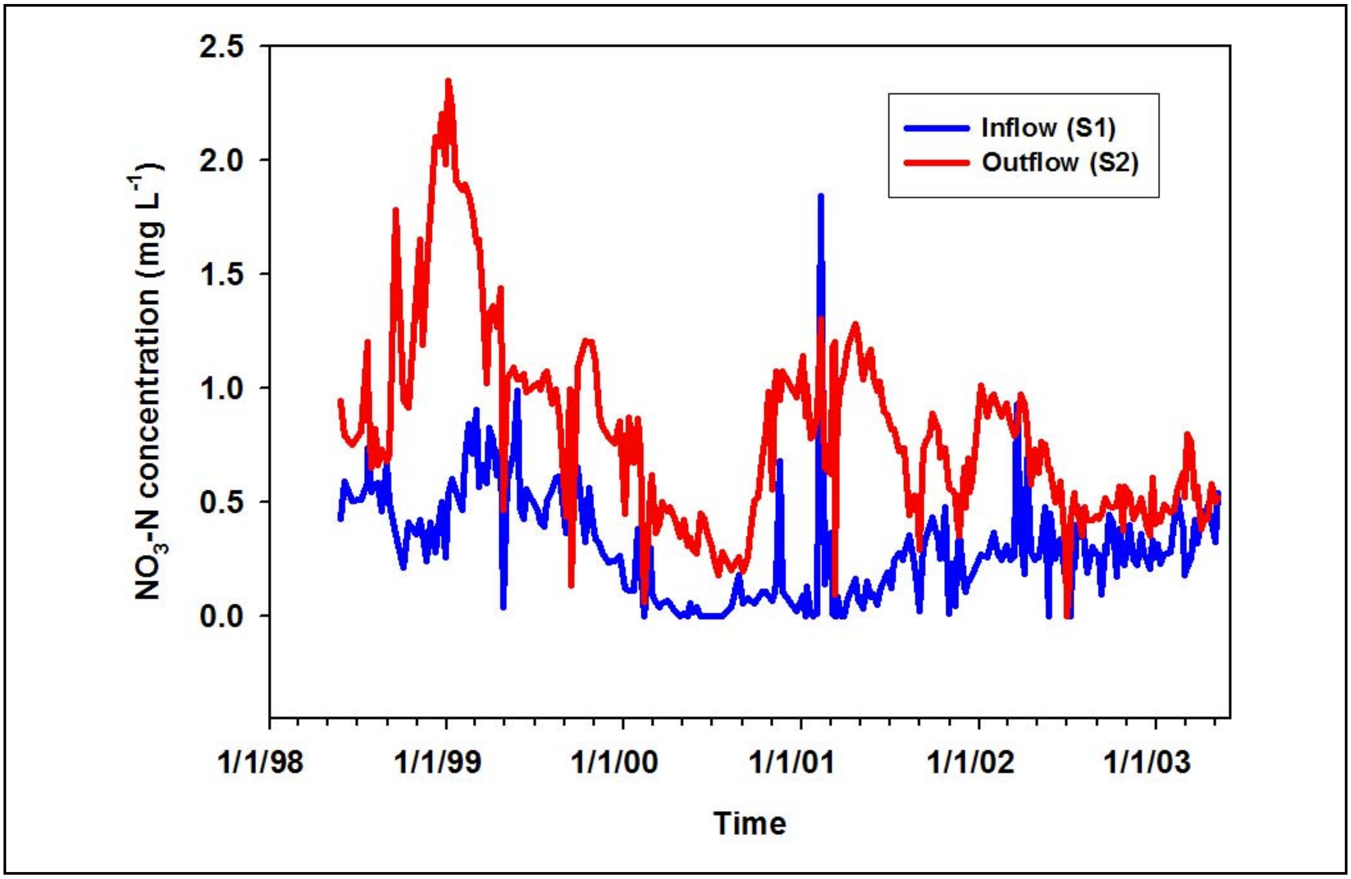

Figure 4. Inflow and outflow nitrate concentrations from MWMGC (April 1, 1998 to March 31, 2003).

events during the 5-year study period. Equipment failure prevented complete sample collection on seven events. Based on the collected runoff event data (Table 1), the system contributed statistically significant ($p<0.05$) increases in median NO_3+NO_2-N concentrations (+0.12 mg L^{-1}) and PO_4-P concentrations (+0.03 mg L^{-1}), and decreases in NH_4-N concentrations (-0.01 mg L^{-1}).

To calculate estimates of storm loads, the complete data set for 116 storms and concentration estimates for the other seven storms will be used. Concentrations for the seven events that were not measured will be 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 116 storms will be calculated as the sum of the concentration for each sample multiplied by the time-weighted flow during collection of that bottle. Nutrient loads for the 7 storms without complete sets of samples will be estimated as the median nutrient concentration (from the complete storm samples at that site) multiplied by the storm's flow volume.

For the period of record, the estimated storm flow contributions for the study period due to course runoff were 1.2 kg ha^{-1} yr^{-1} NO_3+NO_2-N, 0.23 kg ha^{-1} yr^{-1} of NH_4-N and 0.51 kg ha^{-1} yr^{-1} PO_4-P. These storm flow amounts represent approximately 3.3% of applied N and 6.3% of applied P over the contributing area for the same period. The relatively high percentage of applied-P losses in storm flow is surprising considering the relative immobility of P in turfgrass soils (45). Current background levels of Olsen extractable P in the soil (0-150 mm, 5.9 inches) ranged from 9

Site 3 Lateral Flow Concentrations

.............(mg L^{-1})..............

	NO_3-N	DRP
25th percentile	0.69	0.09
Median	1.27	0.11
75th percentile	1.58	0.15
Maximum	3.94	0.99
Mean	1.15	0.13

Site 4 Lateral Flow Concentrations

.............(mg L^{-1})..............

	NO_3-N	DRP
25th percentile	0.20	0.07
Median	0.32	0.09
75th percentile	0.64	0.11
Maximum	3.07	0.62
Mean	0.47	0.09

Table 2. Statistical distribution of measured daily nutrient concentrations (mg L^{-1}) in subsurface drainage water. (Site 3 n = 1,339; Site 4 n = 1,461)

mg kg^{-1} in the roughs to 44.5 mg kg^{-1} in the greens. Although the current management strategy is to use a low level phosphorus fertilizer, 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 (13, 37, 40). This may account for the higher 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 (45), the results of this study suggest that soils with relatively high background levels of phosphorus may have the potential for low, but significant, contributions of phosphorus to surface water.

Based on grab sample data (Figure 2), the golf course contributes a significant increase in median concentration of NO_3+NO_2-N (+0.46 mg L^{-1}) to baseflow exiting the course (Table 1). NH_4-N concentrations were reduced in baseflow (-0.06 mg L^{-1}), and the course had no significant effect on PO_4-P concentrations in baseflow (Table 1). 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 (Figure 4) In contrast, NH_4-N levels were consistently higher at the upstream site, and no seasonal patterns were

			Concentration						
Reference	**Land Use**	**Area**	**NH_4**	**NO_3+NO_2**	**TN**	**DRP**	**TP**	**Duration**	**Study Location**
11	common bermudagrass	6 m^2	------	1.3	----	4.2	-----	8 events	College Station, TX
26	90% Kentucky bluegrass 10% red fescue	32 m^2	------	0.87	----	----	-----	2 years	Kingston, RI
9	80% Kentucky bluegrass 20% perennial ryegrass	37.2 m^2	1.44	10.1	----	0.5	-----	18 months	Ithaca, NY
22	bentgrass and ryegrass	123.5 m^2	------	1.47	-----	4.06	-----	2 years	State College, PA
43	13 sites on 5 golf courses	------	------	0.3	0.94	------	0.03	2 years	Ontario, CA
38	native prairie	------	------	------	1.18	------	0.39	3 months	Manhattan, KS
	golf course construction	------	------	------	3.94	------	0.93	20 months	
	golf course maintenance	------	------	------	1.91	------	0.51	4 years	
17	golf course storm events	29 ha	------	0.3	------	0.00	-----	22 events	Austin, TX
	golf course baseflow			0.86	------	0.01	-----	13 months	
This study	**golf course storm events**	**29 ha**	**0.00**	**0.12**	**------**	**0.03**	**-----**	**5 years**	**Austin, TX**
	golf course baseflow		**0.06**	**0.46**	**------**	**0.00**	**-----**		
21	golf course	53 ha	0.3	0.29	1.3	0.05	0.1	2 years	Japan
23	golf course	54 ha	0.04	0.32	------	0.019	----	1 year	New Hanover County, NC
	golf course	53.7 ha	0.03	0.32	------	0.008	----	1 year	New Hanover County, NC
	golf course	NA	0.23	1.46	------	0.005	----	9 months	Brunswick County, NC
	golf course	46.4 ha	0.03	0.06	------	0.056	----	1 year	New Hanover County, NC
	golf course	111.7 ha	-----	0.11	------	0.004	----	1 year	New Hanover County, NC

Table 3. Selected studies identifying nutrient and sediment concentrations (mg L^{-1}) in surface waters from grassed and wooded catchments. (TN = total nitrogen, DRP = dissolved reactive phosphorous, and TP = total phosphorous)

			Concentration						
Reference	**Land Use**	**Area**	**NH_4**	**NO_3+NO_2**	**TN**	**DRP**	**TP**	**Duration**	**Study Location**
16	60% tall fescue; 40% Kentucky bluegrass (fertilized)	10 m^2	0.09	0.06	0.17	0.05	0.02	18 events	Upper Marlboro, MD
	60% tall fescue; 40% Kentucky bluegrass (non-fertilized)		0.05	0.04	0.08	0.02	0.01		
35	'Tifway' bermudagrass	25.2 m^2	--------	3.05	-------	-------	------	4 years	Griffin, GA
9	80% Kentucky bluegrass 20% perennial ryegrass	37.2 m2	0.35	0.90	------	0.12	------	18 months	Ithaca, NY
5	bermudagrass (putting green)	0.025 ha	--------	0.52	------	-----	------	3 months	College Station, TX
	bermudagrass (fairway)	1.57 ha	---------	0.96	------	-----	-------		
17	golf course storm events	29 ha	--------	2.1	------	0.3	-------	22 events	Austin, TX
	golf course baseflow		--------	4.3	------	0.05		13 months	
This study	**golf course storm events**	**29 ha**	**0.23**	**1.20**	**------**	**0.51**	**-----**	**5 years**	**Austin, TX**
21	golf course	53 ha	1.7	3.7	13.5	1.6	3.04	2 years	Japan

Table 4. Selected studies identifying nutrient loads (kg/ha/yr) in surface waters from grass plots and golf courses. (TN = total nitrogen, DRP = dissolved reactive phosphorous, and TP = total phosphorous)

observed. PO_4-P concentrations were similar at both sites and steady throughout the year.

NO_3-N and DRP in Subsurface Flow

For the four-year period of subsurface sample data collection, measured median NO_3-N concentration at Site 3 was 1.27 mg L^{-1}, while median DRP concentration was 0.11 mg L^{-1} (Table 2). Measured median concentrations at Site 4 were 0.32 mg L^{-1} NO_3-N and 0.09 mg L^{-1} DRP (Table 2). NO_3-N and DRP concentrations from Site 3 were significantly ($p<0.05$) greater than concentrations detected at Site 4. Greater NO_3-N and DRP concentrations measured at Site 3 are indicative of greater and more frequent fertilizer applications to greens compared to fairways.

There was a weak relationship ($r^2 = 0.55$) between daily discharge and NO_3-N concentration at Site 4; however, no relationship was detected for DRP and discharge at Site 4. A similar analysis conducted for Site 3 showed no relationship between drainage discharge and NO_3-N or DRP. Concentrations of NO_3-N and DRP at Site 3 and Site 4 were generally positively correlated through time. This correlation suggests that weather factors influence the timing of nutrient movement in the French drain (constant across the experimental site), although the magnitude of concentration in the drainage water may have been influenced by management (different for each sampling site).

Based on flow measurements (13 months at Site 3 and two years at Site 4), median daily flow at Site 3 was 0.6 m^3 (1.8 m^3 ha^{-1}), while median daily flow at Site 4 was 8.2 m^3 (11.1 m^3 ha^{-1}). No significant relationship between monthly discharge from the French drains and precipitation (Figure 4) was detected (Site 3 $r^2 = 0.25$; Site 4 $r^2 = 0.13$). Flow from the French drains was continuous throughout the year, most likely a result of irrigation. The difference in flow magnitudes at Site 3 and Site 4 could result from differences in topography, contributing area, length and depth of drain, and/or seepage from an unknown source contributing to Site 4, although a hydrogeologic survey of the site was not conducted.

In the case of seepage from an unknown source contributing to Site 4, measured concentrations at that site may also be impacted. The measured nutrient load attributed to the course at Site 4 may be either over- or under-estimated depending on the volume and nutrient concentration of the seepage water. The estimated average annual combined load of NO_3-N in the drainage water associated with Site 3 (0.77 kg ha^{-1}) and Site 4 (1.92 kg ha^{-1}) was 2.7 kg ha^{-1} (approximately 2.5% of the amount applied on the study area). This amount is comparable to, but less than, the value of 3.8 kg ha^{-1} yr^{-1} reported by Mitchell et al. (26) on a grass system in Illinois and the value of 10.7 kg ha^{-1} yr^{-1} documented by Ruz-Jerez et al. (34) for intensively managed ryegrass in New Zealand. In contrast, the average NO_3-N loading from corn and corn/soybean crop production systems is reported to be in the range of 5-100 kg ha^{-1} yr^{-1} (14, 20, 21, 26, 33).

The estimated average annual combined DRP load transported through the French drains at Site 3 (0.08 kg ha^{-1}) and Site 4 (0.38 kg ha^{-1}) was 0.46 kg ha-1 (an amount equivalent to 2.0% of the applied). This amount is considerably greater than loadings recorded from drainage water on a corn production system (0.04 kg ha^{-1} yr^{-1}; 20). DRP losses in subsurface drainage water can be substantial when conditions for leaching are favorable or promoted or when preferential flow is present (9, 15, 18). The Houston Black soil present in this study area is susceptible to preferential flow (1) and may explain the greater transport of DRP. In addition, leaching can be substantial in sandy soils like those found in the green.

How Does This Study Compare?

While only a few studies have been conducted on watershed-scale turf systems, it is important to understand how this study relates. The NO_3-N and DRP concentrations measured in this study are on the low end of the range of concentrations reported from other plot and watershed-scale turf studies (Table 3). Nutrient loadings measured in this study are also comparable to those reported from both plot and watershed scale turf studies (Table 4). DRP loads were on the high end of the range of reported loads.

Turf managers are often faced with multiple options for managing turf. They are asked to balance turf quality and growth with climate, soil, vegetative conditions, and management practices. Their choice of practice is critical for controlling and/or reducing surface runoff and pollutant transport.

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