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Dr. Kevin King, Agricultural Engineer for the US Department of Agriculture, concluded from water quality monitoring at Northland Country Club in Dulth, MN, that nitrogen losses on the course, while statistically significant, pose little environmental threat. However, phosphorus losses , while small in magnitude, exceeded the concentrations linked to eutrophication.

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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 350 projects at a cost of $29 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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Hydrologic and Water Quality Assessment from Managed Turf

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SUMMARY

Water quality of Northland Country Club in Duluth, MN has been monitored over four years (2003-2006) to measure and assess the small watershed-scale hydrologic and surface water quality impact from a golf course watershed. The study's findings include:

- Runoff plus tile flow from this course expressed as a percentage of rainfall was equivalent to 47%.
- The nitrogen fertilization regime used on this course appears to pose little risk for significant inorganic nitrogen transport in surface runoff.
- The measured phosphorus concentrations indicate the need for thorough soil sampling prior to additional phosphorus application. This includes characterization of soils saturated with precipitated phosphorus.
- Nitrogen and phosphorus loadings from this course were generally greater than or similar to losses from native prairies and forests but less than loadings reported for agriculture.
- 2,4-D and chlorothalonil concentrations and loads are consistent with those previously reported on plot-scale studies.

Turf systems, including golf courses, turf farms, city parks, residential and institutional lawns, roadsides, and cemeteries are an integral component of the landscape. In 1993, turf area in the United States was estimated at 46.5 million acres (1). The economic inputs associated with turf range from $58 per acre on roadsides to approximately $1,650 per acre on golf courses (1). Demand for high quality turf systems has led to intensive management strategies that include cultural, physical, and chemical approaches. The management of turf, in both rural and urban areas, has major natural resource conservation implications.

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Environmentally sound management of golf course turf provides both public and private facilities with environmental, cultural, and economic benefits. There are approximately 16,000 golf courses operating in the United States (24). 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 (3, 5).

The perception and potential for nutrients and pesticides to be transported in surface water is well documented (4, 19, 29, 26, 30, 26). Management of existing golf courses and construction of new facilities is often a "lightning rod" of environmental and water quality concern (3). Whether or not that concern is warranted is often debated because of limited information on water quality exiting golf courses. High quality watershed scale data are needed to adequately address this issue.

Previous studies (8, 10, 12, 22, 23) have addressed runoff volume and nutrient loss from turf. However, these studies focused on small areas from plots up to individual greens or fairways (7, 16). The data collected from plot studies

Eventually all surface drainage on the golf course migrates toward Lake Superior.

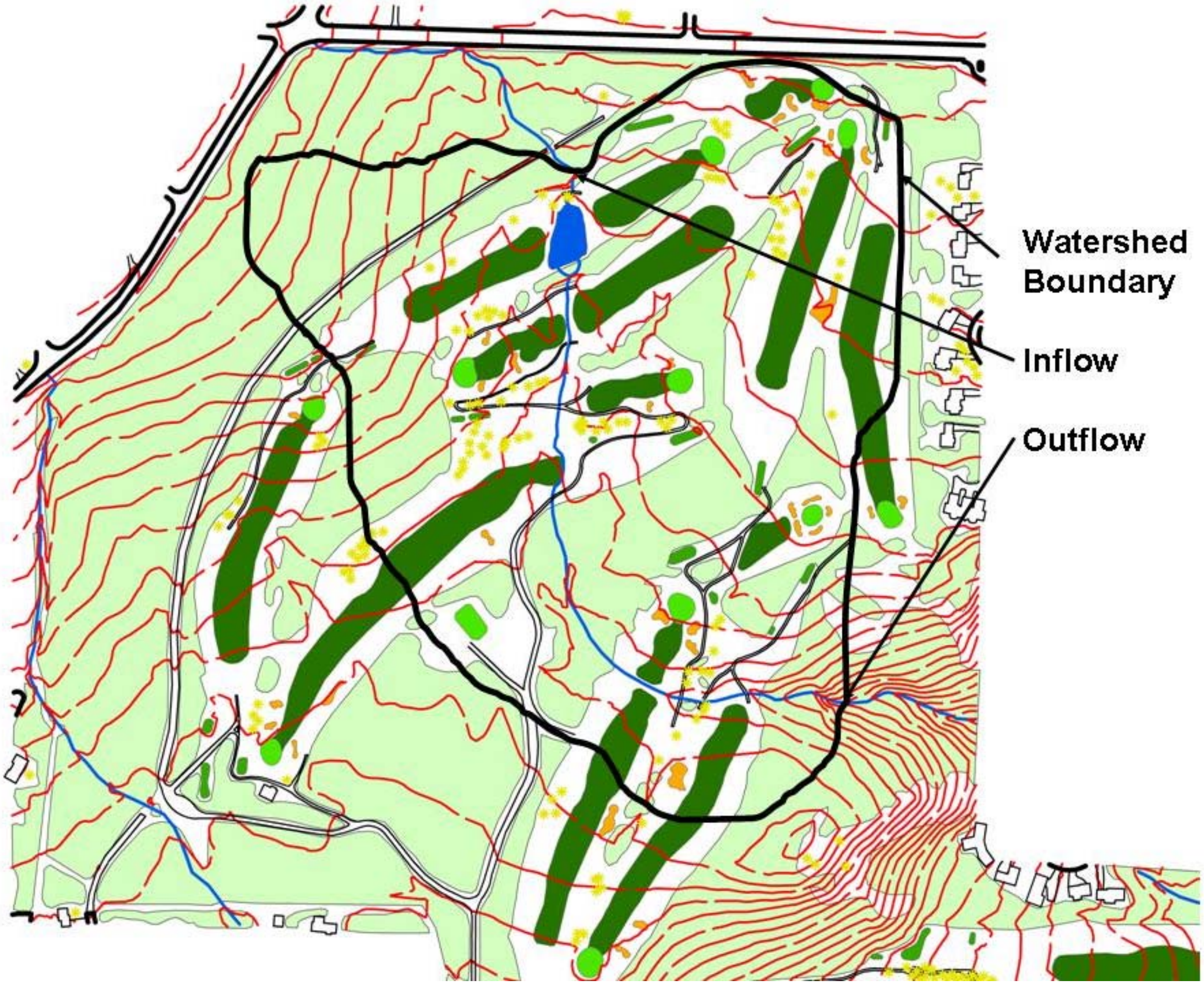

Figure 1. Layout of NCC and identification of area used for this study

is also limited with regard to the temporal domain. Studies on small scales are valuable, but they may not represent the diversity and connectivity associated with a complete turf system. Cohen et al. (7) emphasizes the need for field-scale water quality studies on golf courses.

The primary objective of this research was to measure and assess the small watershed-scale hydrologic and surface water quality impact from a golf course watershed in an effort to test the following hypothesis: nutrient losses in surface runoff from a watershed scale recreational turf system (golf course) is not significant.

Experimental Site

The experimental site is part of Northland Country Club (NCC), located in Duluth, MN. NCC has several sub-watersheds or drainage areas with unnamed streams draining into Lake Superior. The study area is located along a stream on the northeastern part of the golf course (Figure 1). This area forms a discrete drainage area composed of six complete holes, three partial holes, and unmanaged areas of mixed northern hardwoods and bedrock outcroppings. The 21.8-ha drainage area is comprised of 8 greens (0.3 ha), 8.5 fairways (4.0 ha), 8 tees (0.5 ha) and 17 ha of unmanaged trees (9.0 ha) and grass (8.0 ha).

The managed turf area accounts for 21.7% of the measured golf course drainage area. The drainage stream enters a natural pond located at the top of the small watershed. This stream then bisects the study area. There is a 37-meter elevation change across the study area with slopes ranging from 3 to 25%. Approximately 80 ha of low density housing and forested area feed the inflow site. A small area of typical urban housing is located on the east side of the inflow portion of this upper watershed.

NCC is in a temperate-continental climatic region. The area is characterized by warm, moist summers and cold, dry winters. The average monthly maximum summer temperature (May - August) ranges from 16º C to 25º C (62º F to 77º F) while the average monthly maximum winter temperature (December - March) ranges from -9º C to 0º C (16º F to 32º F). Normal annual precipitation is 780 mm (30.7 inches), half of which is generally frozen. The stream bed at the outlet is typically frozen solid from the end of November through the end of March.

NCC soils are characteristic of lacustrine clay deposits, moderately deep (3 to 6 m) over bedrock. The dominant soil on NCC is the Sanborg (fine, mixed, active, frigid, Oxyaquic Glossudalfs) -Badriver (fine, mixed, active, frigid Aeric Glossaqualfs) complex. Previous references to the soils located on NCC identified the soils as Cuttre, Ontonagon, and Bergland soils. however, more recent soil surveys have identified the soils as Sanborg-Badriver complex. All of these soils have very similar morphological, chemical, and physical characteristics. The parent material is noncalcareous, clayey lacustrine deposit over calcareous clays. Perched water table conditions on the site are common and are caused by the dense subsurface horizons and fine-textured soils.

Management practices during the study period were typical of courses in the upper mid-west. Greens and tees were seeded with creeping bentgrass (*Agrostis palustris* Huds. *stolonifera* L.). Fairways were a mixture of creeping bent-grass and Kentucky bluegrass (*Poa pratensis* L.). The roughs were a mixture of annual bluegrass (*Poa annua* L.) and Kentucky bluegrass. NCC was irrigated with potable water from the city of Duluth. Irrigation was applied on an "as needed" basis, determined by course personnel, to replace

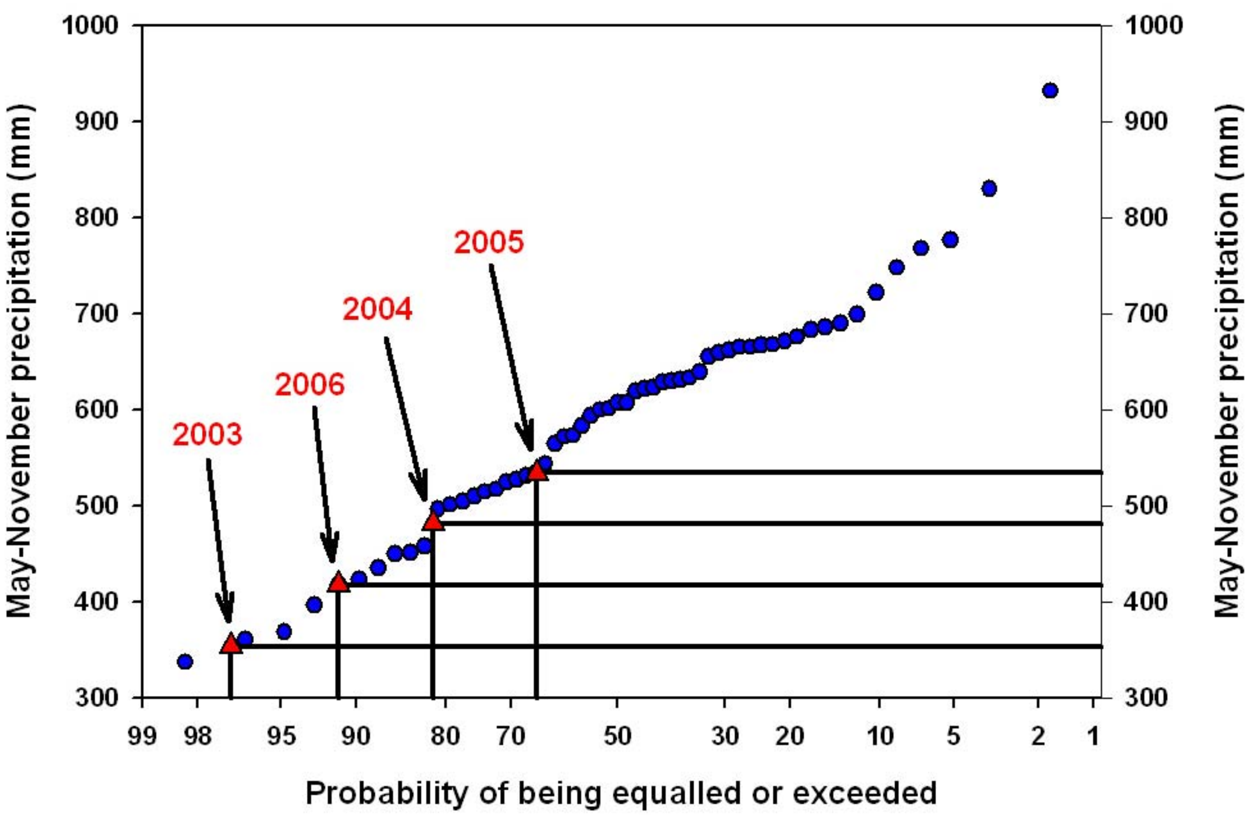

Figure 2. Exceedance probability plot for annual precipitation recorded at NCC during the four year study period

Management Unit	Grass	Fertilizer ($kg\ ha^{-1}\ yr^{-1}$) N	P	Irrigation ($mm\ yr^{-1}$)
greens	creeping bentgrass (C.B.)	82	52	225
tees	creeping bentgrass	188	89	240
fairways	C.B. and Kentucky bluegrass (K. B.)	96	59	215
roughs	annual bluegrass and K. B.	24	1	0

Table 1. Nutrient and irrigation management summary for NCC during the period 2003-2006. 1 kg/ha equals 0.89 lb/acre and 1 inch equals 25.4 mm.

evaporative losses. Fertilizer was applied by both dry broadcast and spray techniques throughout the year as a combination of organic, bio-stimulant, slow-release, and fast-release formulations.

NCC uses a moderate level of nitrogen fertilizer and a small level of phosphorus fertilizer, primarily applied as slow-release formulations. The number of applications in any one year is dependent on plant needs; however, the average fertilizer applications per year in 2003 and 2005 ranged from two applications on the fairways to 13 applications on the greens. Based on a review of soil test data at the golf course, Bray available phosphorus concentrations in the fairways, tees, and greens were ranked as high to very high (generally > 60 mg/kg).

Data Collection and Analysis

Surface water quantity and quality instrumentation was installed in June 2002. H-flumes (3 ft) were installed at the inflow and outflow locations of the study area to measure discharge. Automated Isco samplers attached to bubbler flow meters, as well as tipping bucket rain gauges, were also added at each site to collect samples for water chemistry analysis. Automated samplers were active from April 15 to November 30, the period when the stream was generally not frozen.

Temperatures can and often do exceed the freezing point during the non-sampling period. However, the durations of these 'thaw' periods are small producing only minimal flows compared to the flows measured during the primary sampling period. Additionally, equipment limitations limit the ability to continually sample throughout the year. However, the stream was monitored on a daily basis. If flow was observed, grab samples were collected, as well as stream stage samples.

During the primary sampling period, discharge and precipitation were recorded on ten-minute intervals. Discrete water samples were collected using a flow proportional approach. Samples were collected in 350-mL glass bottles. Ice was carried to the field on a regular basis during the sampling to preserve the samples. Samples were collected immediately following the storm or on weekly basis when no storm events occurred.

Following collection, all samples were handled according to U.S. EPA method 353.3 for nitrogen analysis and U.S. EPA method 365.1 for phosphorus analysis (35). Samples were stored below 4° C and analyzed within 28 days. Samples were vacuum filtered through a 0.45 micrometer pore diameter membrane filter for analysis of dissolved nutrients. Concentrations of nitrate plus nitrite (NO_3+NO_2-N) and dissolved reactive phosphorus (PO_4-P) were determined colorimetrically by flow injection analysis using a Lachat Instruments QuikChem 8000 FIA Automated Ion Analyzer.

NO_3+NO_2-N was determined by application of the copperized-cadmium reduction and PO_4-P was determined by the ascorbic acid reduction method (25). Total nitrogen (TN) and total phosphorus (TP) analyses were performed in combination on unfiltered samples following alkaline persulfate oxidation (20) with subsequent determination of NO_3-N and PO_4-P. From this point forward NO_3+NO_2-N will be expressed as NO_3-N. Here, PO_4-P is used synonymously with dissolved reactive phosphorus (DRP) and will be designated from this point forward as DRP.

Analysis for chlorothalonil and 2,4-D was conducted using enzyme-linked immunosorbent assay (ELISA) and methods outlined by Strategic Diagnostics Inc (31, 32). Once collected in the field, samples were stored at or below 4 °C until analysis, usually less than one week. The samples were first filtered through a 0.45 micrometer pore diameter membrane filter. Once filtered, a prescribed sample volume was added to the base of pre-labeled test tubes followed by 250 microliters of the enzyme conjugate and then 500 microliters of magnetic particles. Each sample tube was then mixed and allowed to incubate for 30 minutes.

After incubation, a magnet was applied to the base of the tube and the liquid poured off. One milliliter of wash agent was then added, poured off and repeated. Five hundred microliters of color reagent was then added to each tube, stirred, and allowed to incubate for 20 minutes. Following the incubation period, 500 microliters of an acidic solution was added to stabilize the sample. The samples were then analyzed using a spectrophotometer. Samples exceeding the maximum designed threshold were diluted and reanalyzed.

All statistical analyses were conducted with SigmaStat 3.5 statistical software and methods outlined by Haan (14). Normality was tested using the Kolmogorov and Smirnof test and a significance level equal to 0.05. Distributions were generally not normally distributed, thus median values collected at the inflow and outflow points were tested using the Mann-Whitney nonparametric statistic with a significance level of 0.05.

Results

Hydrology

Annual precipitation during the four-year study period was below normal. The greatest annual precipitation (533 mm in 2005) had a 65% probability of being equaled or exceeded in any given year (Figure 2). The duration and total volume of discharge is directly related to precipitation and antecedent soil moisture. Increasing precipitation intensity increases the flow of runoff water and energy available for nutrient and pesticide extraction and transport. The more intense the rainfall, the less time required to initiate storm runoff.

Annual discharge volumes (combination of baseflow and storm-event runoff) for the study period were equivalent to approximately 47% of the precipitation volume (Table 2). The deep to moderately deep clayey soils on this course have some increased risk of surface runoff. The 0.47 discharge coefficient measured on NCC was considerably greater than discharge coefficients reported on turfgrass plots (10, 27), suggesting

				Upland		Upland + NCC		NCC	
Year (Apr-Nov)	Rainfall (P) (mm)	Max. Int. (mm/hr)	Max. 24-hr Precip (mm)	Disch. (Q) (mm)	Q/P (%)	Disch. (Q) (mm)	Q/P (%)	Disch. (Q) (mm)	Q/P (%)
2003	353	18.5	37.1	64	0.18	82	0.23	147	0.42
2004	482	22.3	51.3	118	0.24	143	0.30	235	0.49
2005	533	23.9	74.9	166	0.31	195	0.37	302	0.57
2006	418	19.1	50.5	96	0.23	110	0.26	161	0.39

Table 2. Measured precipitation, intensity, and discharge for upland site, upland plus NCC, and NCC during data collection period April through November.

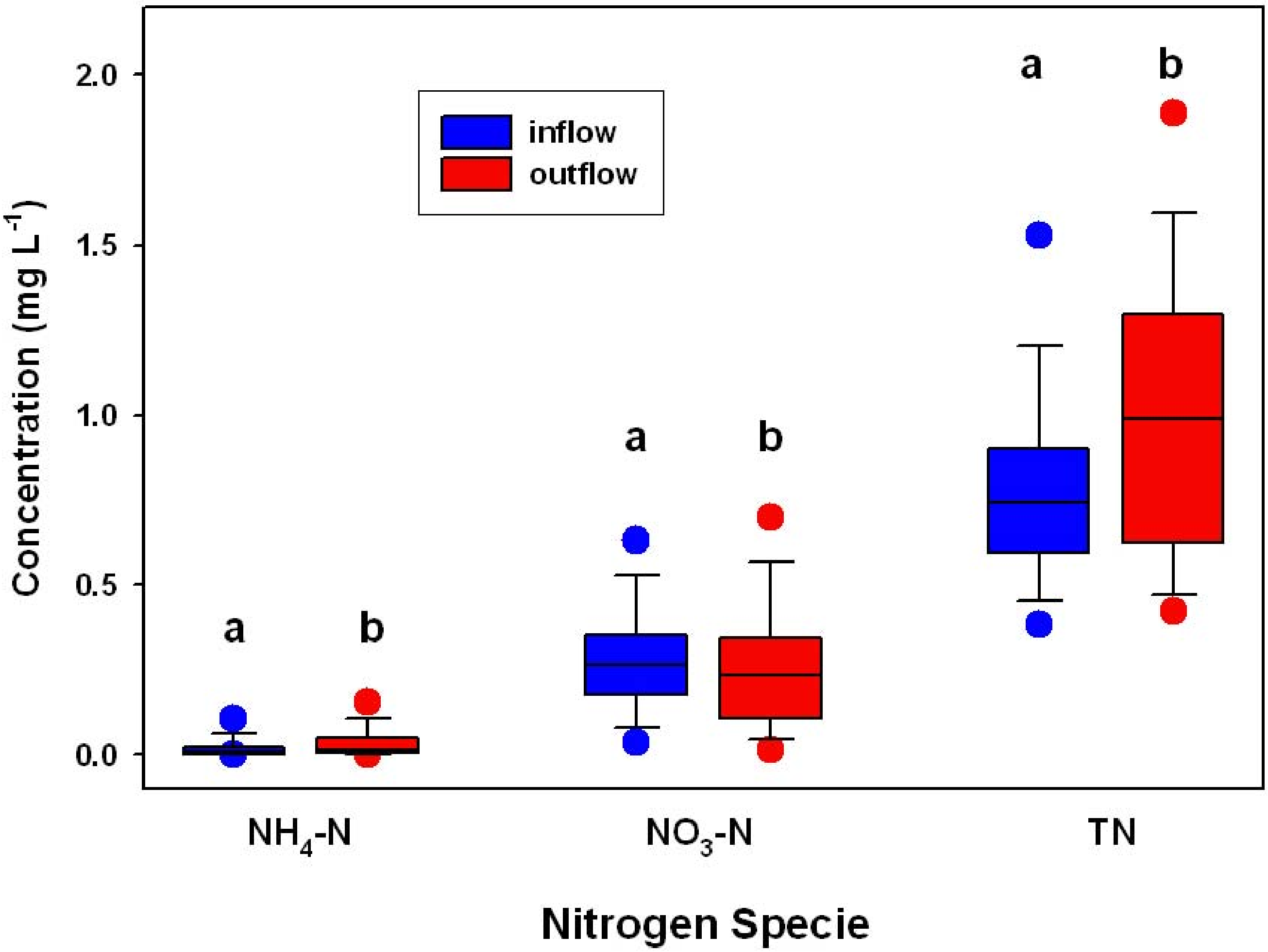

Figure 3. Inflow and outflow concentrations of NH_4-N, NO_3-N, and TN at NCC during the study period 2003-2006. Bar graphs are bound by the 25th (lower) and 75th (upper) percentile concentrations. Whiskers represent the 10th and 90th percentile concentrations. The points below and above the whiskers are the 5th and 95th percentile. The line in the box represents the median. For each constituent, different letters over the boxes indicate significant ($p<0.05$) differences in median values.

that not only are the processes governing the hydrology at the two scales different, but that further hydrologic assessments to understand those processes need to be initiated on watershed-scale golf course systems.

Nutrients

A range of nutrient concentrations were measured from the course (Figures 3 and 4). Median concentrations of NO_3-N were below 1 mg L^{-1} and the maximum recorded concentrations were well below the EPA drinking water standard of 10 mg L^{-1}. In fact, the median NO_3-N outflow concentration was significantly less than the inflow concentration. NH_4-N, TN, DRP, and TP concentrations were significantly greater ($p < 0.05$) in the outflow compared to the inflow. The magnitudes of the nitrogen concentrations suggest that the nitrogen fertilizer management regime used on this course does not pose a significant environmental threat.

The measured phosphorus concentrations were consistent with concentrations shown to cause eutrophic conditions in lakes, ponds, and streams (28). Increases in phosphorus concentra-

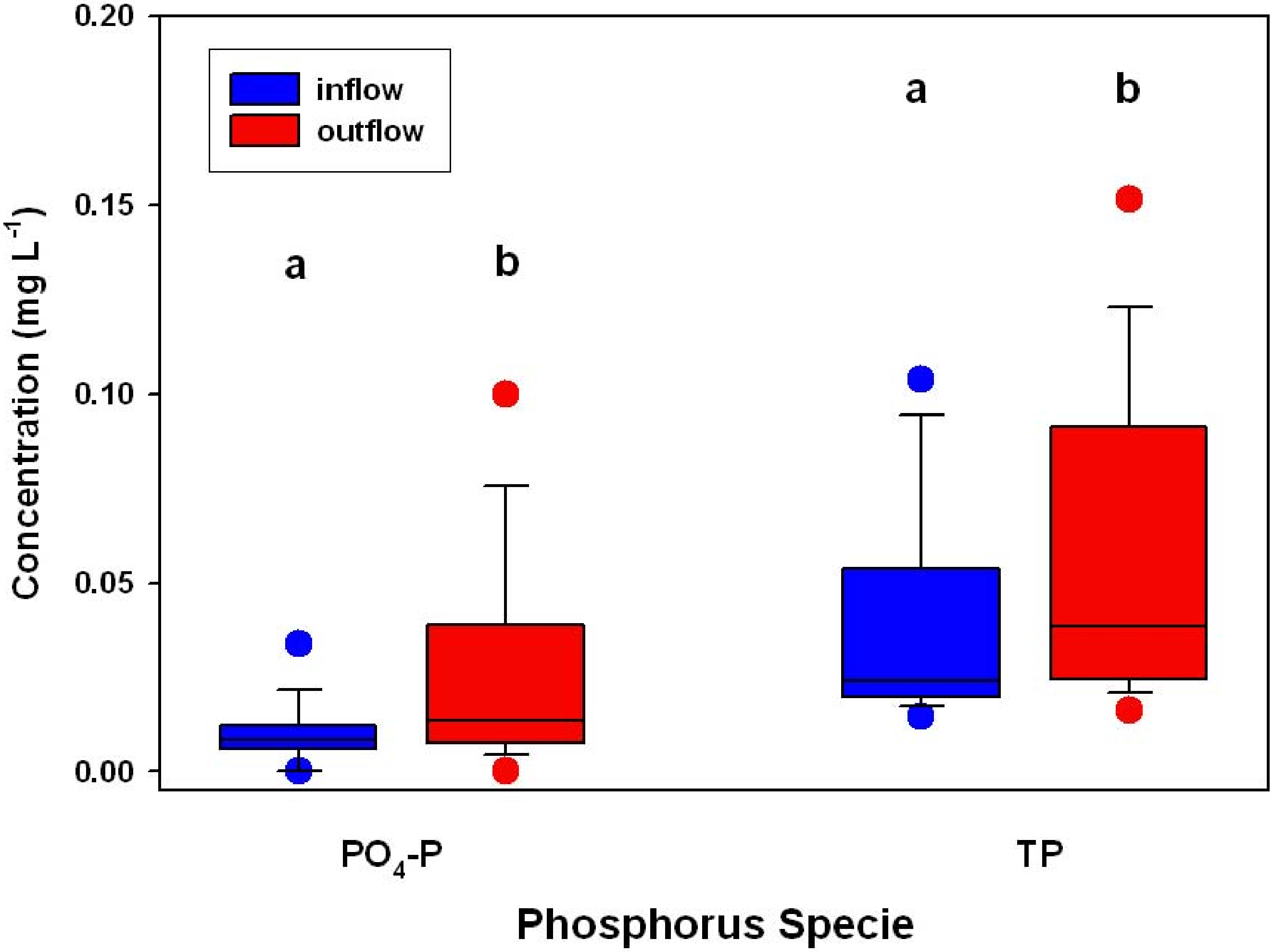

Figure 4. Inflow and outflow concentrations of DRP and TP during the four-year study period 2003-2006. Bar graphs are bound by the 25th (lower) and 75th (upper) percentile concentrations. Whiskers represent the 10th and 90th percentile concentrations. The points below and above the whiskers are the 5th and 95th percentile. The line in the box represents the median. For each constituent, different letters over the boxes indicate significant ($p<0.05$) differences in median values.

tion were generally noted with precipitation events. The results from this study suggest that using slow-release fertilizers and appropriate application methods mitigate the elevated potential for movement of chemicals to streams on the golf course. Additionally, maintenance of high quality turfgrass (37), the accumulation of thatch and organic matter in the topsoil (33, 39), and use of integrated best management practices also reduces the risk of nutrient losses (11, 36, 38).

Nutrient loadings (the mass of nutrient transported in surface flow) from NCC were calculated from the concentration data and the measured runoff from the course. Nutrient load attributed to the course was 0.02 kg ha^{-1} yr^{-1} NH_4-N, 0.62 kg ha^{-1} yr^{-1} NO_3-N, 0.14 kg ha^{-1} yr^{-1} DRP, 3.3 kg ha^{-1} yr^{-1} TN, and 0.24 kg ha^{-1} yr^{-1} TP. The loadings from this golf course are generally greater than or similar to loadings reported for native prairies (34) and forested catchments (13, 21) but less than loadings reported for agriculture (9, 15), the exception being phosphorus (Table 3).

Despite the relative immobility of phosphorus in soil (36), the results of this study suggest that this course may have the potential for small, but significant, contributions of phosphorus

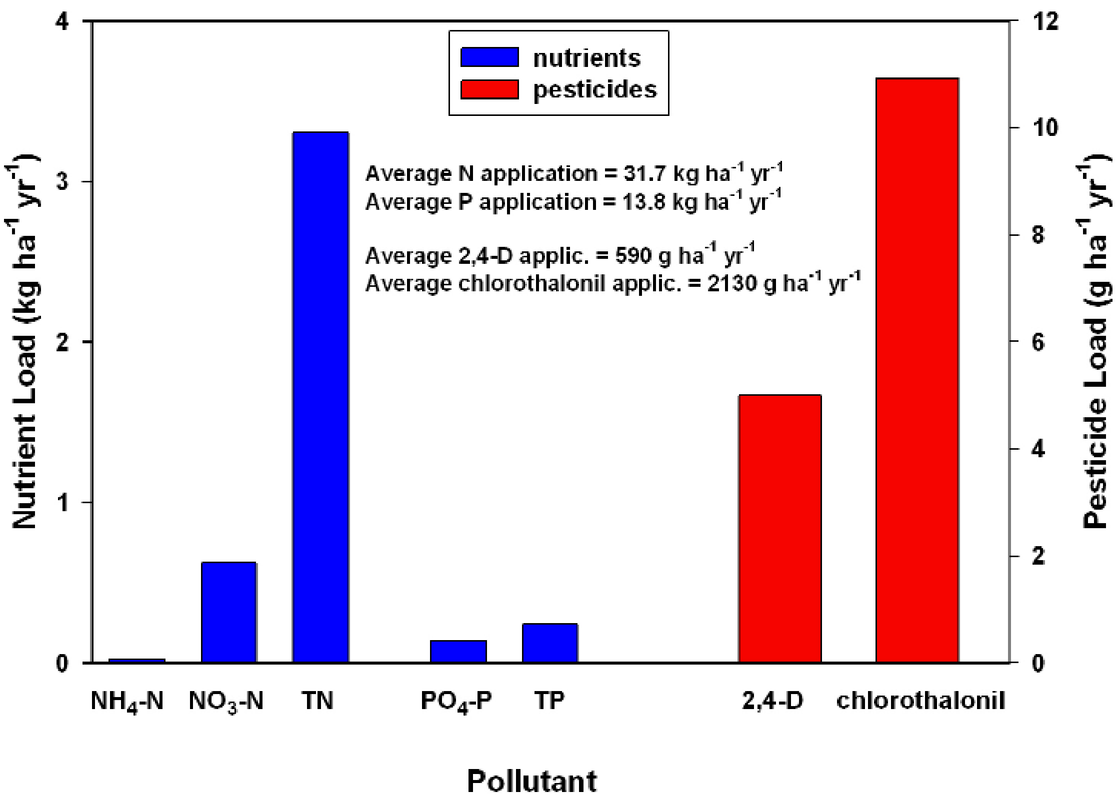

Figure 5. Bar graph of mean annual nutrient and pesticide loads for NCC during the study period 2003-2006

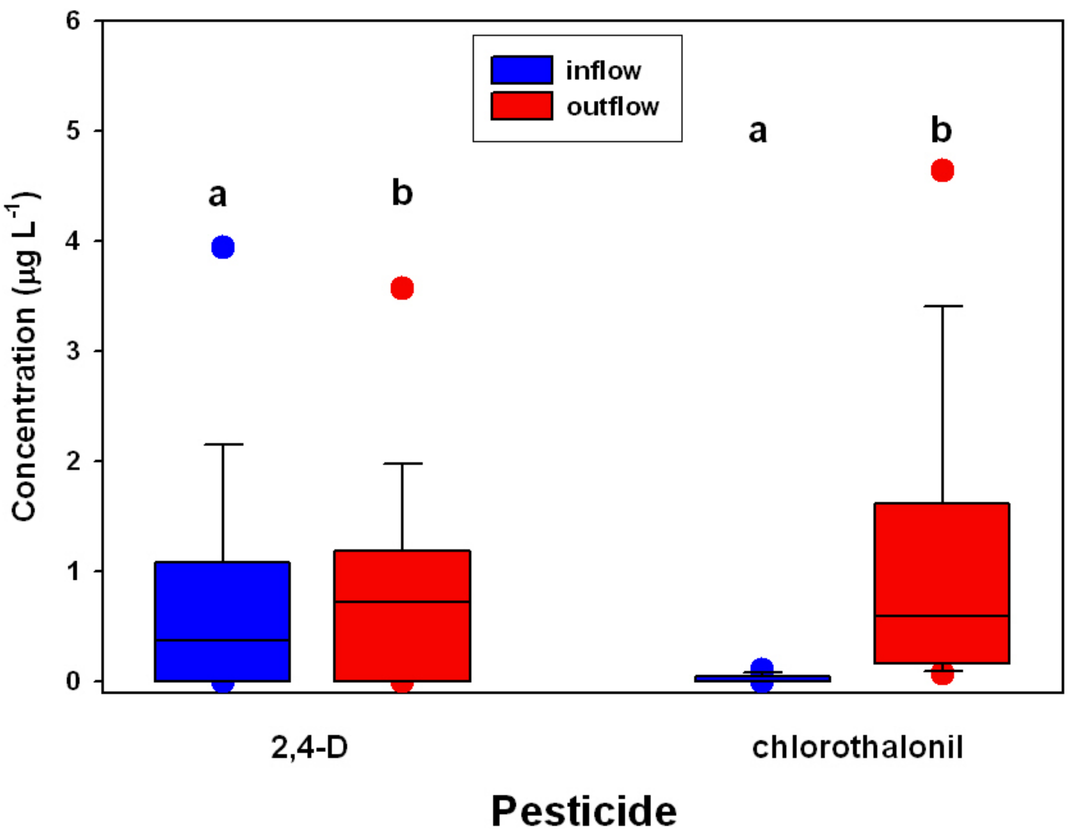

Figure 6. Inflow and outflow concentrations of 2,4-D and chlorothalonil during the four-year study period 2003-2006. Bar graphs are bound by the 25th (lower) and 75th (upper) percentile concentrations. Whiskers represent the 10th and 90th percentile concentrations. The points below and above the whiskers are the 5th and 95th percentile. The line in the box represents the median. For each constituent, different letters over the boxes indicate significant ($p<0.05$) differences in median values.

Reference	Land use	Area	NH_4	NO_3	TN	DRP	TP	Duration	Study Site
27	'Tifway' bermudagrass	25.2 m^2	------	3.05	------	------	------	4 years	Griffin, GA
10	80% Kentucky bluegrass; 20% perennial ryegrass	37.2 m^2	0.35	0.90	------	0.12	------	18 months	Ithaca, NY
34	native prairie	89.6 m^2	0.14	0.12	0.84	0.02	0.11	5 years	Big Stone County, MN
6	bermudagrass green;	0.025 ha	------	0.52	------	------	------	3 months	College Station, TX
	bermudagrass fairway	1.57 ha	------	0.96	------	------	------		
18	golf course: storm events	29 ha	------	2.1	------	0.3	------	13 months	Austin, TX
	golf course: baseflow		------	4.3	------	0.05	------		
17	golf course	29 ha	------	4.0	------	0.66	------	5 years	Austin, TX
21	golf course	53 ha	1.7	3.7	13.5	1.6	3.04	2 years	Japan
	forest	23 ha	0.2	4.1	5.4	0.03	0.13		
9	95% agriculture; 5% urban	327 ha	0.34	20.4	-----	0.28	1.13	1 year	Fayette County, KY
	43% agriculture; 57% urban	506 ha	0.95	10.8	------	0.13	1.14		
	99% urban; 1% agriculture	226 ha	0.52	5.97	------	0.07	0.66		
15	agriculture	214 ha	1.15	5.68	25.6	0.07	3.72	3 yrs	Westmoreland County, VA
This study	**golf course**	**21.8 ha**	**0.02**	**0.62**	**3.3**	**0.14**	**0.24**	**4 years**	**Duluth, MN**

Table 3. Nutrient loads (kg ha^{-1} yr^{-1}) from NCC and other selected land uses

to surface water. The TN loading from this course was equivalent to 10.4% of the nitrogen applied to the course, while the TP loading was 1.7% of the applied phosphorus.

Pesticides

Chlorothalonil and 2,4-D concentrations were measured at the inlet and outlet of the study area for the four year period (Figure 6). The median outlet concentrations for both pesticides was significantly greater ($p<0.05$) than the median inlet concentrations throughout the study period, suggesting that pesticide application and management may be responsible for the increases. In the case of 2,4-D, significant increases were not only a result of course management but also apparent applications to home lawns and right-of-ways in the upland area.

Chlorothalonil losses were entirely the result of applications on the golf course. The losses of chlorothalonil were quite surprising and not expected given the relative immobility of the chemical. None of the 2,4-D concentrations measured exceeded the published health standard of 70 micrograms L^{-1}. Chlorothalonil does not have a registered health standard. The greatest concentration measured was 48.1 micrograms L^{-1}.

Pesticide loads attributed to the course were calculated as the difference in loading at the inflow and outflow site divided by the contributing area. The calculated loads were 5 g/ha/yr 2,4-D and 10.9 g/ha/yr chlorothalonil. The losses of pesticides were equivalent to 0.9% of the applied 2,4-D and 0.5% of the applied chlorothalonil. The concentrations and percent recovery are consistent with reports by Armbrust and Peeler (2) and Smith and Bridges (30) for the same chemicals.

Conclusions

A long-term watershed scale assessment of hydrology and water quality was initiated in late 2002 on a golf course in Duluth, MN. Discharge, nutrient, and pesticide variables have been measured throughout the study period. Discharge from the course expressed as a percentage of rainfall was 47%. Nitrogen losses on the course, while statistically significant, pose little environmental threat. However, phosphorus losses, while small in magnitude, exceeded the concentrations linked to eutrophication. Pesticide losses were relatively small and consistent with previously reported concentrations and percentages recovered.

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