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Golf Course Watershed Management for Reduction of Nutrient and Pesticide Losses to Surface Water

Golf course managers recognize the importance of keeping nutrients and pesticides on the golf course and preventing offsite movement into surface waters such as streams, reservoirs, and lakes. Research on a Minnesota golf course highlights the importance of watershed scale investigations for development of effective best management practices to significantly reduce nutrients and pesticides from leaving your golf course.

There are approximately one million hectares of golf course turf in the United States. Since 1992 the golf course industry and many turfgrass managers have focused their efforts on development of environmentally sound golf course management.[1,5,9] In the urban landscape golf courses are the most intensively managed land use, leading to a perception that golf course management significantly contributes to environmental degradation by offsite movement of nutrients and pesticides.[3,10,13]

Nutrient applications on golf courses are used to promote healthy, dense turfgrass. Due to its dynamic characteristic in soil, available nitrogen levels tend to decrease over time and require regular additions. Phosphorus usually enhances the rate of turfgrass establishment from seed or vegetative plantings. Phosphorus is generally needed during the start-up or green-up phase but subsequent applications may be reduced. Nutrient enrichment is a primary cause of water quality impairment in the United States and the world.[2]

Use of herbicides and fungicides are an important component of maintaining healthy turfgrass. Two commonly used pesticides on golf courses are 2,4-D and chlorothalonil. Chlorothalonil is one of the most widely used fungicides in the United States. Recreational turfgrass usage by golf courses makes up approximately 10 percent of the total usage of chlorothalonil. Chlorothalonil and 2,4-D have been observed in surface waters associated with golf courses at low concentrations with occasional large concentration spikes.[6,12] Regionally and nationally, it has been recognized by scientists and the public that migration of pesticides from areas of application may pose substantial risk.[9,15]

Golf course managers recognize the importance of keeping nutrients and pesticides on the golf course and avoiding offsite movement into surface waters. The importance of developing watershed scale practices to substantially reduce offsite losses of management chemicals is the foundation of environmentally sound golf course management. Cooperative watershed scale research to monitor and develop effective

In addition to surface runoff, nutrients and pesticides can sometimes find their way into surface drainage inlets. This research project examines part of the Northland Country Club watershed located in Duluth, Minnesota

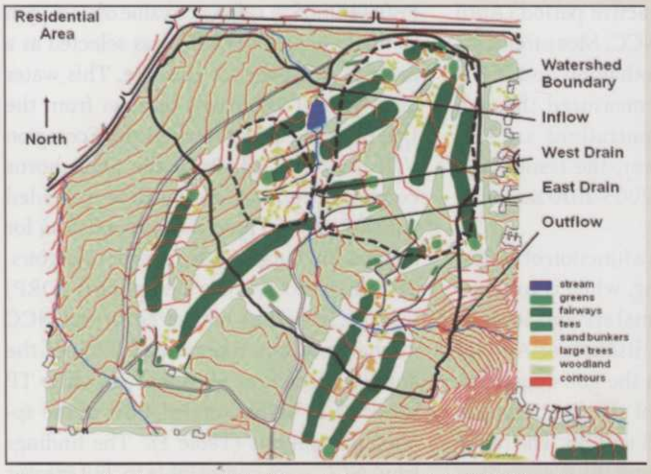

Figure 1. Study area of Northland Country Club (NCC) golf course.


Figure 2. Installed H-flume at Northland Country Club (NCC) in Duluth, MN.

BMPs to reduce offsite movement of management chemicals has been conducted from 2003 to 2013 at Northland Country Club in Duluth, Minnesota. This research is supported by the United States Golf Association and conducted by the USDA Agricultural Research Service and Spectrum Research, Inc.

EXPERIMENTAL APPROACH. The experimental site is a 21.8 ha sub-area of Northland Country Club (NCC) golf course located in Duluth, MN. The study area contains 7 greens (0.3 ha), 8 tees (0.5 ha), 10.5 fairways (3.95 ha), grass roughs (8.1 ha), and 8.95 ha of unmanaged mixed northern hardwoods (Figure 1). A small stream enters the study area at the inlet and empties into a small detention pond and water hazard. After the water leaves the pond it meanders approximately 700 meters through the study area until it exits at the outflow collection site and eventually into Lake Superior. Approximately 80 ha of low density housing and forested area feed the inflow site.

Northland Country Club soils are clayey deposits, moderately deep (3 to 6 m) over bedrock. The site is located in a temperate-continental climatic region. The average monthly maximum summer temperature (May - August) ranges from 16°C to 25°C while the average monthly maximum winter temperature (December - March) ranges from -9°C to 0°C. The stream bed at the inlet and outlet is typically frozen from the end of November through the end of March. Average annual (1949-2008) precipitation measured at the Duluth International Airport during the period of April-November was 648 mm.

Northland Country Club is managed at a moderate to intense level. Greens and tees are seeded with creeping bentgrass. Fairways are primarily creeping bentgrass with some Kentucky bluegrass. The roughs are a mixture of annual bluegrass and Kentucky bluegrass. During the study period the course did go through one change in superintendents altering the approach to management. Nutrient application at NCC is considered moderate and is a combination of organic, biostimulant, slow release, and fast release formulations applied by both dry broadcast and spray techniques. More recently the approach has been to move toward an organic approach with reduced applications. Nitrogen fertilization is greatest in May and June and gradually decreases through the remainder of the playing season. Similarly, phosphorus application is greatest in May. Phosphorus application throughout the remainder of the management season is similar but generally less than May applications.

Pesticide application at NCC is primarily used for weed and disease control. Aerial weighted chlorothalonil application averaged 3.2 kg/ha of active ingredient (a.i.). Chlorothalonil is primarily used to retard snow mold and is generally applied in late fall to the primary playing areas. However, it is also used in smaller spot applications during the growing season to treat dollar spot and other turfgrass diseases. 2,4-D is applied throughout the year to control broadleaf weeds. Aerial weighted annual 2,4-D a.i. application was 1.1 kg/ha. 2,4-D is regularly applied to the roughs; however, occasional use on the primary playing areas does occur. During the study period, chlorothalonil and 2,4-D were applied in sprayable formulations.

Hydrology and water quality samples were collected by a combination of grab samples and automated sample collection. In summer of 2002, two three foot H-flumes with stilling wells and approach sections were installed in the stream that bisects the study area (Figure 2). One flume was positioned at the inflow while another was placed at the outflow. Precipitation was collected at the inlet and outlet using tipping bucket and standard rain gauges. Isco 6700 automated samplers were programmed to collect discrete flow proportional samples every 132 m3 (35,000 gallons).

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	Upland	Upland + NCC	NCC
	DRP (kg/ha)		
2003	0.00	0.02	0.11
2004	0.02	0.05	0.17
2005	0.03	0.08	0.25
2006	0.01	0.02	0.07
Period 1Average	0.015	0.043	0.15
2007	0.02	0.04	0.11
2008	0.03	0.05	0.13
2009	0.02	0.02	0.02
2010	0.05	0.06	0.09
Period 2 Average	0.03	0.043	0.088
Annual Average	0.022	0.04	0.12
	TP (kg/ha)		
2003	---	---	---
2004	0.06	0.11	0.29
2005	0.05	0.11	0.36
2006	0.02	0.04	0.09
Period 1 Average	0.043	0.087	0.247
2007	0.04	0.07	0.18
2008	0.09	0.16	0.33
2009	0.04	0.05	0.08
2010	0.14	0.15	0.20
Period 2 Average	0.078	0.108	0.198
Annual Average	0.06	0.10	0.22

Table 1. Annual loading of dissolved reactive phosphorus (DRP) and total phosphorus (TP) from upland site, upland plus NCC, and NCC during data collection period April through November for Period 1 (2003-2006) and Period 2 (2007-2010).

Concentrations of NO3+NO2-N and PO4-P were determined colorimetrically by flow injection analysis using a Lachat Instruments QuikChem 8000 FIA Automated Ion Analyzer. Total nitrogen (TN) and total phosphorus (TP) analyses were performed concurrently on unfiltered samples. Analysis for chlorothalonil and 2,4-D was conducted using enzyme linked immunosorbent assay (ELISA) and methods outlined by Strategic Diagnostics Inc.14 Nutrient and pesticide loads were calculated by multiplying the analyte, nutrient and pesticide concentration, by the measured water volume for that respective sample. The volume of water associated with any one sample was determined using the midpoint approach.

FINDINGS. Rainfall, stream discharge, nitrogen, phosphorus, chlorothalonil, and 2,4-D concentrations and loadings were measured during the hydrologic active period (April 1 to November 30) at NCC. Measurements began in 2003. Chlorothalonil and 2,4-D concentrations were measured through 2009. Nutrient concentrations are still being collected; however, the results presented here reflect the 2003-2010 sampling period.

Hydrology at NCC is a function of winter thaw in the early spring, while convective thunderstorms and frontal systems account for summer and fall discharge. Annual surface discharge from the golf course expressed as a fraction of the precipitation (Q/P) ranged from 0.43 to 0.86. The range of Q/P ratios was substantially greater than the 0.18 Q/P ratio determined from a 5-yr golf course study in Austin, TX and the 0.17 to 0.34 Q/P ratio range reported for urban and suburban watersheds around Baltimore, MD. However, the Q/P ratio at NCC was comparable to the 0.47 runoff fraction reported for a 1.5 year study on a subarea of a golf course in North Carolina. The higher runoff fraction is directly related to the clay soils at NCC.

NITROGEN. Nitrate-nitrogen (NO3-N) concentrations as low as 0.05 to 0.1 ppm were observed in outflow at NCC. In marine estuaries even these low NO3-N levels contribute to eutrophication. Total nitrogen (TN) concentrations as low as 1 to 2 ppm promotes and sustains algal growth in marine estuaries. Maximum NO3-N concentration measured in the outflow at NCC was 1.9 ppm. The median NO3-N concentration was 0.25 ppm. In total, 85% of all NCC outflow (n = 1317) NO3-N concentrations exceed the 0.1 ppm eutrophic threshold. The median TN concentration for this study was 1.08 ppm. Fifty-three percent of the outflow TN concentrations were greater than 1 ppm.[7]

At NCC the mean annual NO3-N load (0.7 kg/ha) represented 1.7% of the applied nitrogen while the average annual TN load (4.43 kg/ha) represented 10.7% of the applied nitrogen. The TN captured in the discharge waters was comparable to the 5% TN recovered for two golf courses in Canada, but substantially less than the 32% recovered in drainage waters on a course in Japan.[11,16]

PHOSPHORUS. A reference value of 0.05 ppm as total phosphorus (TP) was selected as a basis of reference for this site. This water quality level was based on data from the USEPA ambient water criteria for Ecoregion VIII. At NCC, 13.2% of the phosphorus concentrations in the outflow exceeded the USEPA 0.05 ppm recommendation for streams discharging into lakes or reservoirs. The dissolved reactive phosphorus (DRP) load (0.12 kg/ha) recovered in the NCC discharge waters represented 2.6% of the applied elemental phosphorus, while TP losses (0.22 kg/ha) totaled 4.6% of the applied phosphorus (Table 1).[7] The findings from NCC were comparable to, but greater than, the 2% phosphorus recovery from two golf courses in Canada, but markedly less than the 14% reported for a golf course in Japan.[11,16]

From 2003 to 2010 there was a distinct decline in the amount of phosphorus applied to the course (Table 2).[9] During this same period, the phosphorus applied to the course also shifted from inorganic to organic formulations. Thus, the study period was divided into two distinct time periods. The first or "before" time period (Period 1, 2003-2006) is representative of more traditional phosphorus fertility management on golf courses using inorganic formulations (mono-ammonium phosphate, di-ammonium phosphate, and to a lesser extent, ammoniated normal super phosphate, triple superphosphate, and calcium meta-phosphate). The second or "after" period (Period 2, 2007-2010) represents a more progressive and environmentally aware approach to fertility management and primarily use of organic formulations (fish extract, liquid seaweed concentrate, yucca and black strap molasses, and compost growers tea).

A smaller percentage of the TP concentrations exceeded the 0.05 ppm threshold in Period 2 (20%) compared to Period 1 (37%). At 50% of the TP threshold or 0.025 ppm, exceedences in both periods were recorded between June and October. However, the number of exceedences in Period 2 (13%) was less than Period 1 (38%).[9]

Mean annual TP concentration (0.047 ppm) during Period 2 was below the 0.05 ppm threshold recommended to maintain a mesotrophic level in stream water (Figure 3). Similarly, flow-weighted DRP concen-

	Greens	Tees	Fairways	Roughs	Total (aerial weighted)	Total Number of Applications	Amount of total P applied in organic form
	kg/ha						%
2003	26.1	60.2	25.8	6.3	8.8	20	1.0
2004	26.9	51.7	27.4	---	6.5	20	5.0
2005	25.3	28.6	32.7	---	6.9	21	0.8
2006	7.5	12.7	21.1	0.6	4.4	19	2.9
Period 1 Average	21.5	38.3	26.8	3.5	6.7	20	2.4
2007	46.0	6.6	9.6	1.4	3.1	25	6.9
2008	6.0	7.2	2.0	---	0.06	64	83.4
2009	0.03	0.02	0.47	---	0.09	77	99.3
2010	2.37	2.38	0.01	---	0.09	111	100.0
Period 2 Average	13.6	4.05	3.02	1.4	0.84	69.3	72.4
Overall Average	17.53	21.18	14.89	2.77	3.74		

Table 2. Locations, number of applications, and rate of elemental phosphorus applications at Northland Country Club (2003-2010).

tration (0.021 ppm) was below 0.025 ppm (50% of the mesotrophic threshold value). TP and DRP concentrations during Period 1 exceeded the 0.05 ppm threshold. TP concentrations in Period 1 were approximately twice the threshold value. There was a greater than 50% reduction in elemental phosphorus applied to the course between the two periods (Period 1 greater than Period 2). The reduction in phosphorus loss occurred as a result of the combined switch to organic phosphorus formulations and reduced rates of application (Table 2).[9]

2,4-D. The maximum 2,4-D concentration measured at the outlet of NCC was 67.1 ppb and is consistent with course applications. The maximum measured 2,4-D concentration approached but did not exceed the 70 ppb maximum contaminant level (MCL). The greatest monthly median 2,4-D load originating from the golf course was in September (2.4 g/ha) followed by losses in October. These losses occurred immediately after peak applications.[6]

CHLOROTHALONIL. The median chlorothalonil concentration measured at the outlet of NCC was 0.58 ppb while the 25th percentile concentration was 0.17 ppb and the 75th percentile concentration was 1.45 ppb. The 95th percentile concentration was 4.12 ppb. The maximum measured chlorothalonil concentration was 48.1 ppb. The greatest chlorothalonil concentrations were observed in October and November, following applications for snow mold retardation in October. The probability of any concentration exceeding the LC50 threshold for rainbow trout (7.6 ppb) was 1.87%.[6,8]

There were 145 rainfall/runoff events during the study period. Eight events with peak concentrations exceeding the LC50 (7.6 ppb) for rainbow trout threshold were identified in the seven year study. The exposure duration of 4 days for the LC50 for rainbow trout was approached on two of the eight, high concentration events, suggesting that this exposure would be lethal for a significant portion of the sensitive organisms.

Greater chlorothalonil concentrations generally occurred with elevated flow rates. These greater flow rates were associated with storm event runoff throughout the year but were clearly evident in the spring and fall.

Elevated chlorothalonil losses were closely related to timing of application. Primary peak concentrations occurred in fall after application while secondary peaks occurred in the spring when residual chlorothalonil was still present. The secondary peaks measured in the spring were a result of its presence in the turfgrass environment, being sorbed to the thatch and soil and its persistence in the environment indicated by its greater degradation half-life.

Application timing prior to a storm event was even more critical in generating concentrations that exceed the threshold than amount of precipitation or runoff volume (Figure 4). There was a marked difference in the concentrations of chlorothalonil generated shortly after application in the fall compared to concentrations generated with spring runoff. Precipitation amount was not as critical as just having a precipitation/runoff event. Five out of the eight events occurring in the fall had approximately 12.7 mm of rainfall or less.[6,8]

RECOMMENDATIONS. Seasonal variations in nutrient concentrations and loading were apparent for all nutrients. In fresh water systems, nitrogen concentrations and loadings from turf systems are less important than they are in saltwater systems. However, phosphorus concentrations and loads are problematic in both fresh and saltwater systems. These variations are a function of hydrology, application timing and rate, and seasonal turfgrass physiology. Concentrations were generally less than concentrations from other land uses. However, export coefficients or mass losses were comparable to other land use categorizations. Similarly, concentrations and loadings of fungicides and herbicides varied annually and were a function of application rate and timing. Adopting BMPs and conservation practices aimed at reducing the offsite transport of both nutrients and pesticides is necessary.

With respect to nutrients, nitrogen and phosphorus, the recommended BMPs are:

- adhering to soil test recommendations or reduced rates should be followed,
- using slow release formulations to significantly reduced both leaching and surface runoff losses of nutrients,
- placing nutrients into the thatch and soil through 'light' irrigation,
- timing of nutrient applications to coincide with turf needs,
- avoiding application if rainfall is expected within 48 hours,
- avoiding fall applications or adhering to judicial use of fall fertilization,
- monitoring irrigation practices in rela-

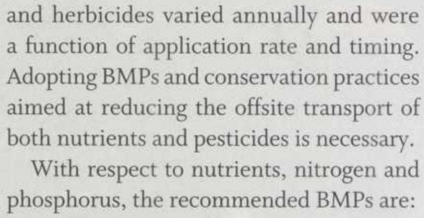

Figure 3. Trend between annual flow-weighted DRP and TP concentrations and applied elemental phosphorus.

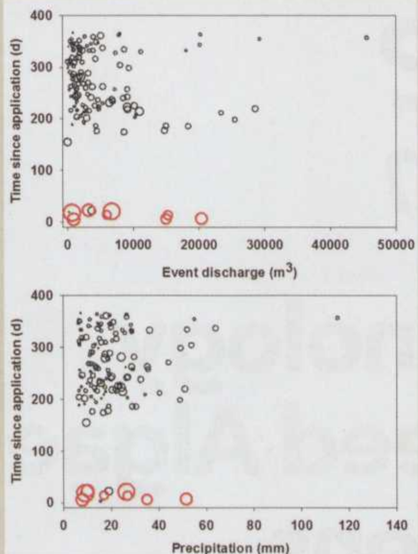

Figure 4. Bubble plot of flow weighted event concentrations (bubbles) and their relationship to precipitation and time since application (lower graph) and their relationship to event discharge and time since application (top graph); the larger the bubbles, the greater the event concentration. The red bubbles correspond to those events with peak concentrations exceeding the reference value of 7.6 mg/L which is equivalent to the LC50 threshold for rainbow trout.

tion to timing of nutrient losses (irrigation can and will promote tile flow, especially on greens),

- adopting the use of organic formulations,
- making multiple low-dose applications rather than fewer large applications,
- installing buffers or route drainage waters through wetlands.

With respect to pesticides and particularly chlorothalonil and its course wide use for snow mold retardation, the recommendations are:

- avoiding application for course wide snow mold protection until after last major rainfalls and before first snow cover events (the label recommendations do allow for multiple applications if snow cover is intermittent),
- using granular and wettable powder formulations rather than liquid or sprayable formulations,
- avoiding application at least 48 hours or longer prior to rainfall,
- installing buffer strips, setbacks, increase buffer strip widths or introduce graduated buffer heights,
- removing clippings,
- maintaining healthy, high density turfgrass to promote infiltration and reduce runoff.

This research conducted on a Minnesota golf course highlights the importance of watershed scale investigations for development of effective best management practices (BMPs) to significantly reduce nutrients and pesticides from leaving your golf course. In general, the development of integrated management plans and implementation of (BMPs) can reduce the environmental footprint of golf courses. An important first step is to seriously consider the fertilizer and pesticide recommendations outlined in this article.

In general, the development of integrated management plans and implementation of (BMPs) can reduce the environmental footprint of golf courses. An important first step is to seriously consider the fertilizer and pesticide recommendations outlined in this article. **GCI**

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