



Hydrology and water quality from managed turf

A long-term watershed-scale assessment showed that nitrogen and pesticide losses from a Minnesota golf course did not pose an environmental threat, but phosphorus losses, although small, exceeded levels linked to eutrophication.



Limited information is available on the quality of water exiting golf courses. Previous studies (for example, 4) have addressed runoff volume and nutrient loss from turf, but these studies focused on small areas from plots up to individual greens or fairways. The data collected from plot studies are also limited with regard to the time period they cover. Small-scale studies are valuable, but they may not represent the diversity and connectivity associated with a complete turf system. To obtain a more-complete picture, high-quality watershed-scale data are needed.

The primary objective of this research was to measure and assess the small-watershed-scale impact of a golf course on hydrologic and surface water quality.

Experimental site

The experimental site is part of Northland Country Club in Duluth, Minn. Northland CC 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 53.9-acre (21.8-hectare) drainage area comprises eight greens (0.74 acre [0.3 hectare]), 8½ fairways (9.9 acres

[4.0 hectares]), eight tees (1.2 acres [0.5 hectare]) and 42 acres (17 hectares) of unmanaged trees (22.2 acres [9.0 hectares]) and grass (19.8 acres [8.0 hectares]).

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 121.4-foot (37-meter) elevation change across the study area with slopes ranging from 3% to 25%. Approximately



A watershed-scale study was conducted at Northland CC in Duluth, Minn., to determine the quality of water exiting the golf course. Photos by K. King



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198 acres (80 hectares) 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.

Climate

Northland CC 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 62 F to 77 F (16 C to 25 C), and the average monthly maximum winter temperature (December-March) ranges from 16 F to 32 F (-9 C to 0 C). Normal annual precipitation is 30.7 inches (780 millimeters), 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.

Soils

Northland CC soils are characteristic of lacustrine clay deposits, moderately deep (9.8-19.7 feet [3-6 meters]) over bedrock. Previous references to the soils located on Northland CC identified the soils as Cuttre, Ontonagon and Bergland soils, but more recent soil surveys have identified the soils as Sanborg-Badriver complex. The dominant soil on Northland CC is the Sanborg- (fine, mixed, active, frigid, Oxyaquic Glossudalfs) Badriver (fine, mixed, active, frigid Aeric Glossaqualfs) 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 are common on the site and are caused by the dense subsurface horizons and fine-textured soils.

Study area

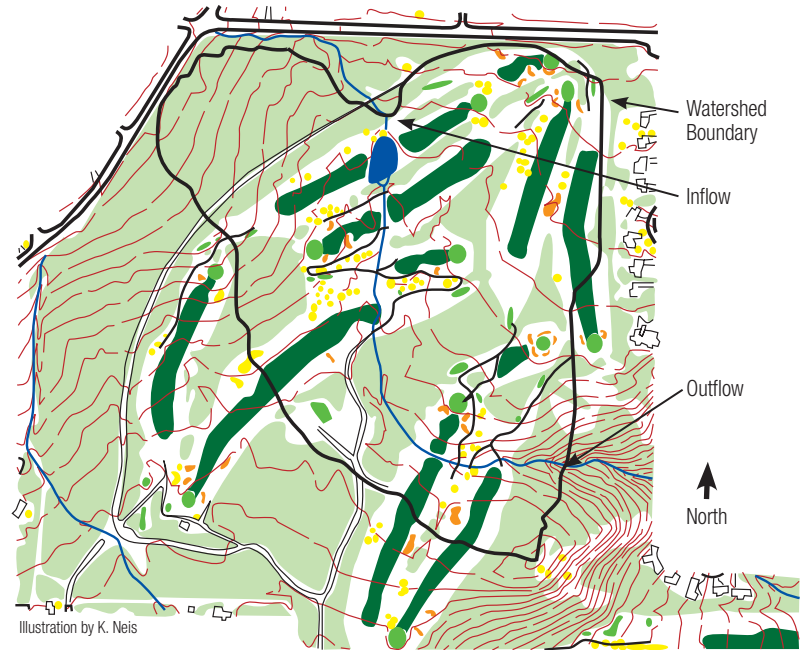


Figure 1. Layout of Northland CC and identification of area used for this study.

Management practices

Management practices during the study period were typical of courses in the upper Midwest. Greens and tees were seeded with creeping bentgrass (*Agrostis palustris* Huds. *stolonifera* L.). Fairways were a mixture of creeping bentgrass and Kentucky bluegrass (*Poa pratensis* L.). The roughs were a mixture of annual bluegrass (*Poa annua* L.) and Kentucky bluegrass.

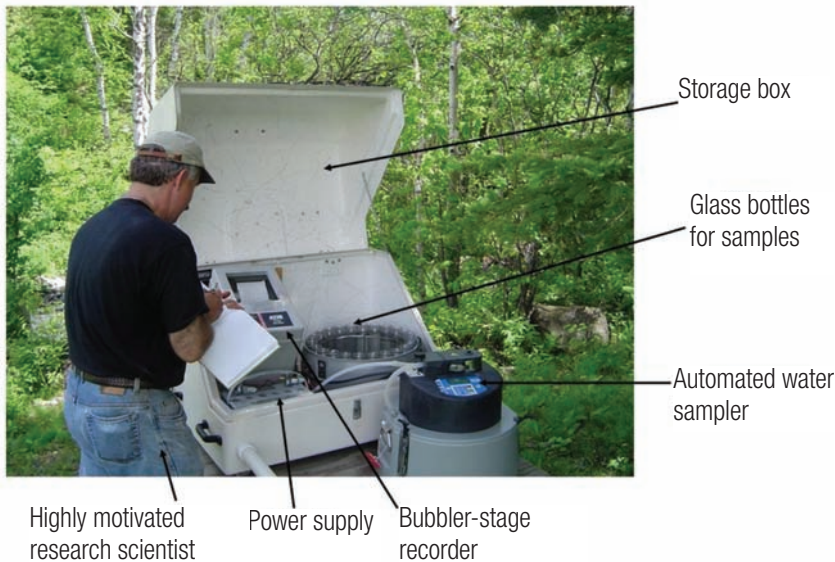
Northland CC was irrigated with potable water

Fertilization and irrigation

Management unit	Grass species	Avg. annual fertilizer				Avg. annual irrigation	
		Kilograms/hectare		Pounds/acre		millimeters	inches
		N	P	N	P		
Greens	creeping bentgrass	82	52	73.2	46.4	225	8.9
Tees	creeping bentgrass	188	89	167.7	79.4	240	9.4
Fairways	creeping bentgrass + Kentucky bluegrass	96	59	85.6	52.6	215	8.5
Roughs	annual bluegrass + Kentucky bluegrass	24	1	21.4	0.89	0	0

N, nitrogen; P, phosphorus.

Table 1. Nutrient and irrigation management summary for Northland CC during the period 2003-2006.



applications on the fairways to 13 applications on the greens. According to a review of soil-test data at the golf course, available phosphorus concentrations (as measured by Bray extract tests) in the fairways, tees and greens were ranked as high to very high (generally >60 milligrams/kilogram).

Data collection and analysis

Surface water quantity and quality instrumentation was installed in June 2002. H-flumes (3 feet [0.9 meter]) were installed at the inflow and outflow locations of the study area to measure discharge. Automated samplers attached to bubbler flow meters and tipping-bucket rain gauges also were added at each site to collect samples for water chemistry analysis. Automated samplers were active from April 15 to Nov. 30, the period when the stream generally was not frozen. Temperatures can and often do exceed the freezing point during the period when samples were not taken, but the durations of these thaw periods are short, producing only minimal flows compared to the flows measured during the primary sampling period. In addition, 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 10-minute intervals. Discrete water samples were collected using a flow-proportional approach. Samples were collected in 11.8-fluid-ounce (350-milliliter) glass bottles. Ice was carried to the field on a regular basis during the sampling to preserve the samples. Samples were collected immediately following a storm or on a weekly basis when no storm events occurred.

Automated samplers collected samples of stream water for chemistry analysis.

from the city of Duluth. Irrigation was applied on an as-needed basis, determined by course personnel, to replace evaporative losses (Table 1).

Fertilizer was applied by both dry broadcast and spray techniques throughout the year as a combination of organic, biostimulant, slow-release and fast-release formulations. Northland CC 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 depends on plant needs, but the average fertilizer applications per year in 2003 and 2005 ranged from two

Rainfall and discharge data, 2003-2006

Year (Apr-Nov)	Rainfall (P) (inches)	Max intensity (inches/hour)	Max 24-hr precip (inches)	Upland		Upland + Northland CC		Northland CC	
				Discharge (Q) (inches)	Q/P (%)	Discharge (Q) (inches)	Q/P (%)	Discharge (Q) (inches)	Q/P (%)
2003	13.9	0.72	1.46	2.51	0.18	3.22	0.23	5.78	0.42
2004	19.0	0.87	2.01	4.64	0.24	5.62	0.30	9.25	0.49
2005	20.9	0.94	2.94	6.53	0.31	7.67	0.37	11.88	0.57
2006	16.5	0.75	1.98	3.77	0.23	4.33	0.26	6.33	0.39

Rainfall (P), maximum 24-hour precipitation and discharge (Q) are expressed in inches; maximum intensity is expressed in inches/hour; 1 inch = 25.4 millimeters.

Table 2. Measured precipitation, intensity and discharge for upland site, upland plus Northland CC and Northland CC during data collection period, April through November 2003-2006.



Following collection, all samples were handled according to U.S. EPA methods for nitrogen and phosphorus analysis. Samples were stored below 39 F (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 (NO₃ + NO₂-N) and dissolved reactive phosphorus (PO₄-P) were determined colorimetrically by flow-injection analysis using an automated ion analyzer.

Analysis for chlorothalonil and 2,4-D was conducted using enzyme-linked immunosorbent assay (ELISA). Once collected in the field, samples were stored at or below 39 F (4 C) until analysis, usually less than one week. After processing, the samples were analyzed using a spectrophotometer.

Results

Hydrology

Annual precipitation during the four-year study period was below normal. The greatest annual precipitation (20.9 inches [533 millimeters] in 2005) (Table 2) had a 65% probability of being equaled or exceeded in any given year (data not shown). 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 base flow 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 Northland CC was considerably greater than discharge coefficients reported on turfgrass plots (6), suggesting 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 (Tables 3, 4). Median concentrations of nitrate plus nitrite were below 1 milligram/liter, and the maximum recorded concentrations were well below the EPA drinking water standard of 10 milligrams/liter. In fact, the median nitrate plus nitrite outflow concentration

Nitrogen inflow and outflow

Percentile	NH ₄ (milligrams/liter)		NO ₃ (milligrams/liter)		Total nitrogen (milligrams/liter)	
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
10th	0.0000	0.0000	0.0838	0.0470	0.4544	0.4740
25th	0.0022	0.0050	0.1788	0.1064	0.5967	0.6250
50th*	0.0126 a	0.0167 b	0.2636 a	0.2351 b	0.7438a	0.9890 b
75th	0.0258	0.0493	0.3510	0.3458	0.8966	1.2943
90th	0.0620	0.1082	0.5291	0.5698	1.1916	1.5909

NH₄, ammonium nitrogen; NO₃, nitrate plus nitrite.

*50th percentile values for each pollutant followed by different letters are statistically different.

Table 3. Distribution statistics for nitrogen in the inflow and outflow waters of Northland CC.

Phosphorus inflow and outflow

Percentile	DRP (milligrams/liter)		Total phosphorus (milligrams/liter)	
	Inflow	Outflow	Inflow	Outflow
10th	0.0000	0.0045	0.0176	0.0209
25th	0.0060	0.0078	0.0199	0.0245
50th*	0.0082 a	0.0136 b	0.0239 a	0.0386 b
75th	0.0125	0.0391	0.0524	0.0911
90th	0.0216	0.0755	0.0941	0.1224

DRP, dissolved reactive phosphorus

*50th percentile values for each pollutant followed by different letters are statistically different.

Table 4. Distribution statistics for phosphorus in the inflow and outflow waters of Northland CC.



Nutrient loads

Ref. No.	Land use	Area	Pounds/acre/year					Duration	Site
			NH ₄	NO ₃	TN	DRP	TP		
10	Tifway bermudagrass	271.3 sq ft	—	2.72	—	—	—	4 years	Griffin, GA
4	80% Kentucky bluegrass; 20% perennial ryegrass	400.4 sq ft	0.31	0.80	—	0.11	—	18 months	Ithaca, NY
13	native prairie	964.4 sq ft	0.12	0.10	0.75	0.02	0.10	5 years	Big Stone Co., MN
2	bermudagrass green	0.06 acre	—	0.46	—	—	—	3 months	College Station, TX
	bermudagrass fairway	3.9 acres	—	0.86	—	—	—		
8	golf course: storm events golfcourse: baseflow	71.7 acres	—	1.87 3.84	—	0.27 0.04	—	13 months	Austin, TX
7	golf course	71.7 acres	—	3.52	—	0.59	—	5 years	Austin, TX
9	golf course	131.0 acres	1.5	3.30	12.04	1.43	2.71	2 years	Japan
	forest	56.8 acres	0.2	3.66	4.81	0.03	0.12		
3	95% agriculture; 5% urban	808.0 acres	0.30	18.20	—	0.25	1.01	1 year	Fayette Co., KY
	43% agriculture; 57% urban	1250.4 acres	0.85	9.63	—	0.12	1.02		
	99% urban; 1% agriculture	558.5 acres	0.46	5.33	—	0.06	0.59		
5	agriculture	528.8 acres	1.02	5.07	22.84	0.06	3.31	3 years	Westmoreland Co., VA
This study	golf course	53.9 acres	0.02	0.55	2.94	0.12	0.21	4 years	Duluth, MN

NH₄, ammonium nitrogen; NO₃, nitrate plus nitrite; TN, total nitrogen; DRP, dissolved reactive phosphorus; TP, total phosphorus.

Table 5. Nutrient loads (pounds/acre/year) from Northland CC and other selected land uses.



A bubbler flow meter was used to measure the depth of streams flowing through the golf course and into Lake Superior.

was significantly less than the inflow concentration. Ammonium nitrogen (NH₄-N), total nitrogen, dissolved reactive phosphorus and total phosphorus concentrations were significantly greater 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 (11). Increases in phosphorus concentration 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, the accumulation of thatch and organic matter in the topsoil and use of integrated best management practices also reduce the risk of nutrient losses (6).

Nutrient loadings (the mass of nutrient transported in surface flow) from Northland CC were calculated from the concentration data and the measured runoff from the course. Nutrient load attributed to the course was 0.017 pound/acre (0.02 kilogram/hectare) per year ammonium nitrogen, 0.55 pound/acre (0.62 kilogram/hectare) per year nitrate plus nitrite, 0.12 pound/acre (0.14 kilogram/hectare) per year dissolved reactive phosphorus, 2.9 pounds/acre (3.3 kilograms/hectare) per year total nitrogen, and 0.21 pound/acre (0.24 kilogram/hectare) per year total phosphorus. With the exception of phosphorus (Table 5), the loadings from this golf course are generally greater than or similar to loadings reported for native prairies (13) and forested catchments (for example, 9) but less than loadings reported for agriculture (3,5). Despite the relative immobility of phosphorus in soil (14), the results of this study suggest that this course may have the potential for small, but statistically significant, contributions of phosphorus to surface water. The total nitrogen loading from this course was equivalent to 10.4% of the nitrogen applied to the course, whereas the total phosphorus 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 (Table 6). The median outlet concentrations for both pesticides was significantly greater 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 resulted not only from course management, but also from 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/liter. Chlorothalonil does not have a registered health standard. The greatest concentration measured was 48.1 micrograms/liter.

Pesticide loads attributed to the course were calculated as the difference in loading at the

Pesticide inflow and outflow

Percentile	2,4-D (micrograms/liter)		Chlorothalonil (micrograms/liter)	
	Inflow	Outflow	Inflow	Outflow
10th	0.0000	0.0000	0.0000	0.0900
25th	0.0000	0.0000	0.0000	0.1600
50th*	0.3700 a	0.7200 b	0.0000 a	0.5900 b
75th	1.0800	1.1800	0.0400	1.6100
90th	2.1100	1.9720	0.0800	3.4000

*50th percentile values for each pollutant followed by different letters are statistically different.

Table 6. Distribution statistics for measured pesticides in the inflow and outflow waters of Northland CC.

inflow and outflow site divided by the contributing area. The calculated loads were 0.07 ounce/acre (5 grams/hectare) per year of 2,4-D and 0.16 ounce/acre (10.9 grams/hectare) per year of 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 previous reports (1,12) 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, Minn. Discharge, nutrient and pesticide variables were measured throughout the study period. Discharge from the course expressed as a percentage of rainfall was 47%. Nitrogen losses on the course, although statistically significant, pose little environmental threat. However, phosphorus losses, although 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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The research says

→ 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 before 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.

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