Water Quality of Golf Courses: What Does The Data Say?

By Michael Bekken, Graduate Student, Department of Soil Science, University of Wisconsin – Madison

Editors Note: Michael Bekken is a Graduate Student pursuing a PhD in soil science under Dr. Doug Soldat. This student article is eligible for the Monroe S. Miller Literary Scholarship.

Show me a stream flowing through a golf course and I'll show you an argument about the impact of golf course management on water quality. Having witnessed these highly emotional, sometimes heated, and commonly speculative discussions firsthand, I've relished the opportunity to delve into the facts from the scientific literature that examine the connections between water quality and golf course management practices. In this report, I review what we know and don't know about the quality of water in and around golf courses and describe the findings of studies designed to assess how management practices affect local water quality.

The impact of golf course management practices on water quality varies widely from course to course and is management dependent. Scientists have studied the connections between golf course management practices and water quality in essentially three different ways. The first approach, taken by five studies reviewed in this article, is to monitor the water quality at a single golf facility. This approach has the advantage of allowing researchers to conduct in-depth and longer-term water quality monitoring. However, because only one site is considered, researchers are not able to look for systematic relationships between the adoption of management practices and water quality. As such, the ability to make general conclusions from this type of study is limited. A second approach, taken by 4 studies included in this article, takes management practices into account when comparing water quality results from various golf courses, which gives researchers the ability to look for trends between the adoption of certain practices and their potential influence on water quality.

I've relished the opportunity to delve into the facts from the scientific literature that examine the connections between water quality and golf course management practices.

Using correlation, this approach has the advantage of being able to determine which management practices may be more effective on water quality than others. However, correlation does not always indicate causation, which is a potential disadvantage of the approach. A third approach, taken by two studies in this article, involves researchers working directly with superintendents to implement best management practices (BMPs) to evaluate their impact on water quality. This type of research approach allows researchers to directly test the effectiveness of a BMP program. However, a drawback of this type of study is that BMPs are often implemented in unison, meaning that it is hard to understand the relative effectiveness of each BMP. A possible fourth approach, would involve researchers working with superintendents to systematically implement BMPs one by one every year. This would allow researchers to gauge the relative effectiveness of each BMP in the field. However, I have not been able to locate any such studies in the current scientific literature. As a result, this article reports on the insight and information gathered from first three types of research design.

In 1999, a group of researchers funded by the Environmental Institute for Golf and led by Stuart Cohen published one of the first reviews of water quality research in and around golf courses. In this study, the researchers solicited reports from all fifty state environmental water quality regulatory agencies and from regional EPA offices that had tracked local water quality around golf courses. Response rates were 37 percent from state agencies and 100 percent from EPA regional offices for data collected between 1990 to 1997. The researchers synthesized results from 17 studies of 36 golf courses, primarily located on the east and west coasts. Taken together, these 17 studies included 16,587 water quality data points in which some number of 136 pesticides, metabolites, and solvents had been analyzed. The authors found that, based on limits set by the EPA for 1999, Maximum Contaminant Levels (MCLs) and Health Advisory Levels (HALs) for the analyzed chemicals were rarely exceeded. Fewer than half a percent of all groundwater and surface water samples exceeded the EPA MCLs or HALs, whereas the percentages of monitoring sites that had at least one MCL/HAL exceedance were slightly higher: 7 percent for groundwater and 6 percent for surface water. This apparent discrepancy derives from the practice of labeling a site as "in exceedance" if any of the samples collected at that site exceed EPA limits during a given study. Importantly, the nitrate MCL of 10 mg/L was not exceeded at any surface water monitoring site but was exceeded in 3.6 percent of groundwater sites. Even though the geographical reach of the study was limited, this preliminary study indicates that golf courses do not commonly exceed the EPA's 1999 water quality contaminant levels.

Following the 1999 publication of Cohen and colleagues' review, the research literature has been dominated by smaller scale studies in which a group of scientists measure water quality at ten or fewer golf courses in the same geographic region, e.g., the coastal southeastern US, the Precambrian Shield crystalline rocks of Ontario, Canada, and a smattering of sites across the central US. (Unfortunately, I did not locate any scientifically peer-reviewed golf course water quality studies from Wisconsin.) In these studies, water quality researchers generally define water quality using chemical and biological indicators. The most frequently measured and ecologically important chemical indicators include nutrient concentrations and pesticide residues, while biological indicators include chlorophyll concentrations, fecal coliform bacteria, heavy metal and pesticide residues in biota, and the structure of macroinvertebrate communities are also monitored in select studies.

Many of the regional studies investigated surface water quality by collecting water samples where a stream enters a golf course (inflow) and again where that same stream exits the golf course (outflow). With this experimental setup, researchers conclude with a fairly high level of confidence that the change in water quality from inflow to outflow can be attributed to golf course runoff. Measuring water quality in streams during non-storm events, referred to as base flow, provides an indication of day-to-day ecological conditions in the water. Additionally, if a researcher wants to understand the total amount of a given contaminant leaving a golf course via the stream, samples also must be taken during storm events, because not only do the largest volumes of water exit the golf course during storm events but with their increased erosive capacity, these events can carry a higher concentration of contaminants than during base flow. In fact, contaminant concentrations have been measured up to an order of magnitude higher in storm runoff waters than in base flow.

Nutrient concentrations in outflow water from golf courses varies significantly among studies and among golf courses. An inflow/outflow study of base flow nitrate concentrations by Michael Mallin and Tracey Wheeler on five golf courses in the coastal region of North Carolina found that concentrations of nitrate increased in outflow waters from three golf courses, did not differ significantly in one, and decreased in one (Table 1). Nitrate concentrations of outflow water from the five golf courses ranged from 0.055 mg/L to 1.46 mg/L. For context, the EPA limit for drinking water is 1 mg/L. Even though the average increase in nitrate was quite low, laboratory experiments by the authors found that increases in nitrate concentration as little as 0.05mg/L could significantly increase eutrophication of surface waters. Small increases in nitrate concentrations do have ecological consequences.

Similarly, phosphate concentrations in surface waters were elevated at two of the five golf courses studied, but the other three were unchanged. The authors did not draw any systematic conclusions as to whether or how best management practices might have influenced the range in concentration of nutrients exiting the golf courses. However, the authors observed that presence of vegetated buffer zones and wetlands designed to treat golf course runoff/effluent seemed to correlate with either stabilized or decreased nutrient concentrations in outflow waters.

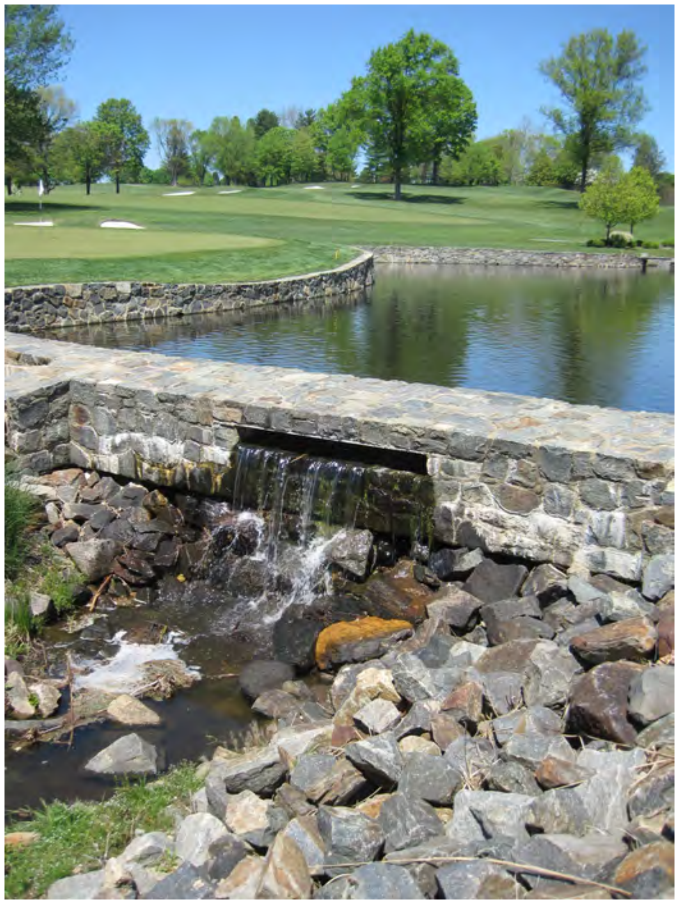

Figure 1. Outflow from a golf course retention pond during base flow conditions.

A separate study in Austin, Texas by Kevin King measured contaminant levels in storm runoff water from one golf course over five years and 115 storm events using an automatic water sampling device. Mean nitrate inflow concentrations were 0.30 mg/L, while mean outflow concentrations were 0.44 mg/L, an increase of 0.09mg/L (Table 1). Phosphate concentrations from inflow to outflow increased but did not reach statistical significance (Table 2). Because the authors measured surface water nutrient concentrations during storm events, they could estimate the total amount of nitrate and phosphate leaving the golf course each year from storm activity, which turned out to be 1.02 kg/ha/yr and 0.51 kg/ha/yr respectively. During the five years of the study the authors did not track best management practices nor how they relate to the observed water quality.

Kevin King, who led the Texas nutrient runoff study, used a similar five-year longitudinal approach to studying pesticide runoff from a golf course in Duluth, Minnesota. King published the Duluth study in 2010, which tracked chlorothalonil and 2,4-D runoff during storm events. Median inflow concentrations of chlorothalonil were below detection while the median outflow concentration was 0.58 µg/L (µg=micrograms, 1,000,000ug = 1 gram). Toxicity levels for trout, in excess of 7.6 µg/L, were occasionally exceeded after application of the pesticide. To place this number in context, the US Health Advisory acute exposure level (HAL) for chlorothalonil is 200 µg/L, and the Canadian guideline for concentrations in natural freshwater is 0.18 µg/L.

Golf course	Mean Inflow Nitrate (mg/L)	Mean Outflow Nitrate (mg/L)	Number of samples	Storm/Non-storm	Statistical Significance
Golf course A: Mallin and Wheeler (2000)	1.08	0.32	12	Non-storm	Significant decrease
Golf course B: Mallin and Wheeler (2000)	0.07	0.32	12	Non-storm	Significant increase
Golf course C: Mallin and Wheeler (2000)	0.005	1.46	18	Non-storm	Significant increase
Golf course D: Mallin and Wheeler (2000)	0.02	0.06	12	Non-storm	Significant increase
Golf course E: Mallin and Wheeler (2000)	Not detectable	0.1	12	Non-storm	Non-significant increase
Golf course A: King et al. (2007)	0.30	0.35	115	Storm	Significant increase
Golf course A: Kohler et al. (2004)	1.38	0.67	6	Storm	Significant decrease

Table 1. Nitrate concentrations in inflow and outflow water from Mallin and Wheeler (2000), King et al. (2007), and Kohler et al. (2004).

Golf course	Mean Inflow Phosphate (mg/L)	Mean Outflow Phosphate (mg/L)	Number of samples	Storm/Non-storm	Statistical Significance
Golf course A: Mallin and Wheeler (2000)	0.028	0.019	12	Non-storm	Non-significant decrease
Golf course B: Mallin and Wheeler (2000)	0.003	0.008	12	Non-storm	Significant increase
Golf course C: Mallin and Wheeler (2000)	0.003	0.005	18	Non-storm	Significant increase
Golf course D: Mallin and Wheeler (2000)	0.038	0.056	12	Non-storm	Non-significant increase
Golf course E: Mallin and Wheeler (2000)	Not detectable	0.004	12	Non-storm	Non-significant increase
Golf course A: King et al. (2007)	0.7	1.4	115	Storm	Non-significant increase
Golf course A: Kohler et al. (2004)	0.31	0.45	6	Storm	Significant increase

Table 2. Phosphate concentrations in inflow and outflow water from Mallin and Wheeler (2000), King et al. (2007), and Kohler et al. (2004).

The median inflow concentration of 2,4-D was 0.31µg/L while the median outflow concentration was 0.85 µg/L. The maximum outflow concentration of 2,4-D over the period of the study was 67.1 µg/L, which approached the EPA's Maximum Contaminant Load (MCL) of 70 ug/L. King showed that transport of 2,4-D from the golf course into the water system correlated positively with streamflow discharge volume, timing of application relative to rainfall events, and pesticide physicochemical properties. He recommended four BMPs to reduce pesticide concentrations in steam outflow including: 1) applying pesticide in less soluble forms (e.g., granular or wettable powder), 2) ensuring no precipitation events are in the near forecast prior to pesticide application, 3) increasing the size and quality of buffer zones around all aquatic bodies, and 4) using spot treatments. However, these best management practices were not tested for their efficacy on the golf course during the study.

A 2007 study conducted by Tracy Metcalfe and colleagues in Ontario tested the toxicity to fish of pesticide runoff. Scientists placed semi-permeable membrane devices at the outflow points of two golf courses throughout the golf season. The devices trapped pesticide residues flowing through the water. These membranes were collected monthly and brought back to the lab to test for contaminant toxicity on developing fish embryos by varying the concentrations of toxins caught in the membranes. Based on these experiments, the authors found that the presence of pentachloronitrobenzene (PCNB) in the spring and fall, a byproduct of the turfgrass fungicide quintozene, corresponded with peaks in toxicity to developing fish. The researchers concluded that the application of this fungicide to a golf course had the potential to cause toxic impacts to aquatic organisms in the watershed. The authors did not assess the BMPs undertaken by the golf course managers, but did note that buffer zones were narrow or lacking in several places where fairways were mown within 1 meter of the sampled stream that drained the majority of the course.

Two studies published by Michael Lewis and others published in 2002 and 2004 were conducted at a large golf complex on Pensacola Bay, Florida, with the goal of determining whether the flora and fauna living in the estuary had been adversely affected by pesticides originating from the golf courses. The authors sampled widgeon grasses (common to estuaries), blue crabs, and oysters in the estuary adjacent to the golf courses for contaminants. They also sampled outflow water from the golf course and from local reference sites in natural areas. Analyses of biota revealed concentrations of 19 different pesticides and 18 polychlorinated biphenyls (PCBs) were largely below detection from all locations. The authors also tested biota for trace metals and found elevated levels both at the golf course and at a local reference site. Chemical analysis of water samples revealed slightly elevated levels of mercury, lead, arsenic, and atrazine near the golf courses, however these elevated levels were only detectable in water samples taken immediately adjacent to the golf course and were not present further into the estuary. The researchers concluded that the golf courses were not a significant source of bioavailable contaminants in the estuary; however, they did not track best management practice implementation at the golf complex to understand how BMPs affect water quality.

In 2002, Jennifer Winter and colleagues published a study of benthic macroinvertebrate communities (i.e. small invertebrate animals found in and around aquatic bodies at some point in their lives) near six golf courses in Ontario and compared the structure of the macroinvertebrate community to that in six nearby forested reference sites in Ontario, Canada. Statistical analysis revealed that the macroinvertebrate communities were significantly impacted at three of the golf course sites, but the other three sites were not statistically distinguishable from the reference sites. In this study, the authors looked for systematic connections between the health of macroinvertebrate communities and the best management practices utilized by the managers of each golf course. Of all of the BMP's included in the analysis, the authors found that fertilizer application rate inversely correlated with macroinvertebrate community health, with lower application rates associated with a healthier community structure.

In a separate 2005 study in Ontario, Jennifer Winter and Peter Dillon investigated the role of riparian quality and its effect on golf course water quality. The researchers monitored chemical water quality on seven golf courses, five of which were operational and two of which were under construction. The researchers simultaneously calculated River Bank Quality Indices (RBQI) for each golf course. The RBQI score accounts for the type of vegetation that surrounds a stream by assigning a number to the vegetation according to its ability to stabilize banks, reduce soil evapotranspiration, regulate stream temperature, and protect against erosion. Using regression analysis, the authors found that higher RBQI scores correlated with lower levels of nitrogen and phosphorus in outflow water. Further, the authors noted lower nitrogen and phosphorus concentrations when the abundance of unmaintained vegetation in riparian areas increased, which effectively act as buffer zones. As in the Ontario study, the authors found that lower fertilizer application rates correlate with lower nutrient levels in outflow streams.

Given the tendency for water quality researchers to suggest the adoption of various best management practices, it is surprising that only two studies have worked with golf course managers to test the effectiveness of these BMPs. In 2001, Nate Davis and Michael Lydy conducted a study in association with the superintendent at a golf course in Wichita, Kansas to evaluate the effectiveness of surface water quality BMPs. The researchers sampled surface water bodies on the course after storm events over a three-year period. In year one, background data were collected and indicated elevated levels of nutrients (nitrates and phosphates) in both ponds and soil. The pesticides simazine and 2,4-D were detected in ponds across the golf course as well as high levels of copper in pond sediment from the use of copper sulfate to control algal growth. An initial benthic macroinvertebrate assessment was conducted which revealed a limited community of only highly contaminant tolerant species. BMP recommendations for year 2 included eliminating the use of copper sulfate, the temporary elimination of phosphorus fertilizer, and the use of a slow release nitrogen fertilizer to reduce nutrient loses. The implemented BMPs worked almost immediately; the average nitrate and phosphate concentrations in the golf course ponds dropped by an average of 46 percent and 41 percent, respectively. During the third year, 30 to 45 ft. wide buffer zones were established around all aquatic bodies in which grass grew to 6 inches with no chemical inputs. Drainage tiles were also rerouted to filtration areas instead of draining directly into ponds. Aquatic vegetation was introduced to the ponds and one pond was dredged to increase depth. At the end of the three years, nitrate concentration in golf course ponds was reduced by 80 percent, phosphate concentration dropped by approximately 50 percent, and the frequency of pesticide detection in ponds also declined.

Macroinvertebrate communities increased in richness and diversity and sensitive taxa indicative of good water quality returned. Because many of the BMPs were implemented simultaneously, the authors were unable to attribute which BMPs were most effective in improving water quality on the golf course. While the implemented BMPs were effective during base flow conditions, they were largely ineffective at reducing pesticide and nutrient release from the golf course during large storm events.

In 2004, E. Kohler and colleagues studied the potential of a series of constructed wetlands on the Purdue University golf course to improve both contaminated urban and golf course runoff water quality. Both an urban stream and tile drainage from the golf course flowed into the wetland system. A total of 83 chemicals were measured at both inflow and outflow sites during storm and non-storm events over a four-year period. During storm events, seventeen contaminants were detected in the inflow water, and eleven of these chemicals were significantly reduced in the outflow water after having passed through the wetland system. Concentrations of aluminum, iron, sodium, and sulfate were occasionally elevated within the wetland system during non-storm events, however during non-storm events there was no discharge of water from the wetland system. As such, the authors determined that the golf course was a non-significant source of contaminants and instead served to improve water quality in the watershed. The authors noted, however, that in order for this type of system to be effective at improving water quality, wetlands must be sized appropriately to maximize water holding capacity during both storm and non-storm events. It is possible that limited water holding capacity of golf course ponds explains why Davis and Lydy in their 2001 BMP study found limited success in reducing offsite transport of pesticides and fertilizers during storm events.

Scientific investigations of golf course water quality indicate that outflow water from golf courses generally contains higher levels of contaminants than in inflow water, but contaminant outflow concentrations only rarely exceed maximum contaminant levels as set by the EPA. However, golf courses have the potential to improve urban and suburban water quality, and some golf courses are already capitalizing on this potential through the implementation of various water quality BMPs. Current studies suggest that the BMPs most effective in improving water quality include: 1) incorporation of chemical free buffer zones with deeply rooted vegetation that shield direct access of runoff to aquatic bodies, 2) reduction in volume of fertilizer and pesticide applied, and 3) structural improvement of onsite drainage and wetland filtration systems. Future scientific studies of golf course water quality will have the greatest impact if scientists work directly with superintendents to implement and test new BMPs while simultaneously monitoring water quality. Ideally these water quality BMPs would be implemented one at a time such that the effectiveness of each BMP can be more precisely determined. And finally, effective water quality BMPs should be tested repeatedly in a wider variety of golf environments.

References:

Davis, N.M. and M. J. Lydy. Evaluating Best Management Practices at an Urban Golf Course. *Environmental Toxicology and Chemistry* 21: 1076-1084.

Cohen, S., A. Svrjcek, T. Durborow, and N.L. Barnes. 1999. Water Quality Impacts by Golf Courses. *Journal of Environmental Quality* 28: 798-809.

King, K.W., J.C. Balogh, K.L. Hughes, and R.D. Harmel. 2007. Nutrient Load Generated by Storm Event Runoff from a Golf Course Watershed. *Journal of Environmental Quality* 36:1021-1030.

King, K.W. and J.C. Balogh. 2010. Chlorothalonil and 2,4-D losses in surface water discharge from a managed turf watershed. *Journal of Environmental Monitoring* 12: 1602-1612.

Kohler, E.A., V.L. Poole, Z.J. Reicher, and R.F. Turco. 2004. Nutrient, metal, and pesticide removal during storm and nonstorm events by a constructed wetland on an urban golf course. *Ecological Engineering*

Lewis, M.A., R.G. Boustany, D.D. Dantin, R.L. Quarles, J.C. Moore, and R.S. Stanley. 2002. Effects of a Coastal Golf Complex on Water Quality Periphyton, and Seagrass. *Ecotoxicology and Environmental Safety* 53: 154-162.

Lewis, M.A., R.L Quarles, D.D. Dantin, and J.C. Moore. 2004. Evaluation of a Florida coastal golf complex as a local and watershed source of bioavailable contaminants. *Marine Pollution* 48: 254-262.

Mallin, M.A. and T.L. Wheeler. Surface Water Quality: Nutrient and Fecal Coliform Discharge from Coastal North Carolina Golf Courses. 2000. *Journal of Environmental Quality*. 29:979-986.

Metcalfe, T.L., P.J., Dillion, and C.D. Metcalfe. 2007. Detecting the Transport of Toxic Pesticides from Golf Courses into Watersheds in the Precambrian Shield Region of Ontario, Canada. *Environmental Toxicology and Chemistry* 27: 811-818.

Winter, J.G., K.M. Somers, P.J. Dillion, C. Paterson, and R.A. Reid. 2002. Surface Water Quality: Impacts of Golf Courses on Macroinvertebrate Community Structure in Precambrian Shield Streams. *Journal of Environmental Quality* 31: 2015-2025.

Winter, J.G. and P.J. Dillion. 2005. Effects of golf course construction and operation on water chemistry of headwater streams on the Precambrian Shield. *Environmental Pollution* 133: 243-253.

The GRASS ROOTS

AN OFFICIAL PUBLICATION OF THE WISCONSIN GOLF COURSE SUPERINTENDENTS ASSOCIATION

VOL. XLVII
ISSUE 4
JULY / AUGUST 2018