Ex 76 #31

ACS SYMPOSIUM SERIES **997**

The Fate of Nutrients and Pesticides in the Urban Environment

Mary T. Nett, Editor
Water Quality Consulting

Mark J. Carroll, Editor
University of Maryland

Brian P. Horgan, Editor
University of Minnesota

A. Martin Petrovic, Editor
Cornell University

Sponsored by the
ACS Division of Agrochemicals

Chapter 5

Discharge Losses of Nitrogen and Phosphorus from a Golf Course Watershed

K. W. King[1], J. C. Balogh[2], and D. Kohlbry[3]

[1]Soil Drainage Research Unit, Agricultural Research Service, U.S. Department of Agriculture, Columbus, OH 43210
[2]Spectrum Research, Inc., 4915 East Superior Street, Suite 100, Duluth, MN 55804
[3]Northland Country Club, 3901 Superior Street, Duluth, MN 55804

Golf course turf accounts for approximately one million hectares of land in the United States, and is the most intensively managed system in the urban landscape. Discharge from golf course turf may potentially transport nutrients into surface water. The primary objective of this research was to assess the small watershed scale hydrologic and water quality impact from a well maintained golf course. The study site was a sub-area of Northland Country Club located in Duluth, MN. Surface water discharge and nutrient concentrations [NO_3-N, NH_4-N, dissolved reactive phosphorus (DRP), TN, and TP] were collected for a 2.5 year period (June 2002-November 2004). The mean measured rainfall/discharge coefficient during the study period was 0.46. Measured NO_3-N and NH_4-N concentrations at the inflow and outflow sites were not significantly different ($p > 0.05$), however, concentrations of TN, DRP, and TP at the same locations were significantly different ($p < 0.05$). Nutrient load attributed to the course was 0.11 kg ha^{-1} yr^{-1} NH_4-N, 0.59 kg ha^{-1} yr^{-1} NO_3-N, 0.14 kg ha^{-1} yr^{-1} DRP, 2.79 kg ha^{-1} yr^{-1} TN, and 0.27 kg ha^{-1} yr^{-1} TP. Nitrogen loads from this site pose minimal environmental concerns; however, phosphorus concentrations are consistent with concentrations known to lead to eutrophic conditions.

Introduction

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 (*1*). 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, 3*). The perception (*4, 5, 6, 7, 8*) and potential (*9*) for nutrients and pesticides 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 watershed scale data are needed to adequately address this issue.

Plot scale turfgrass studies (e.g., *10, 11, 12, 13, 14*) and, to some degree, watershed studies (*15, 16, 17, 18, 19*) have addressed runoff volume and nutrient loss from turf. The plot scale studies generally focused on small areas from plots or individual greens or fairways (20, 21), and the data is often limited to concentrations rather than loadings. Nitrate concentrations from these selected studies were generally less than 10 mg L^{-1}, while phosphorus concentrations ranged from 0.5 to 8 mg L^{-1}. Studies on small scales are valuable, but they may not represent the diversity and connectivity associated with a watershed scale turf system. The watershed scale assessments generally confirm that the concentrations reported in plot scale studies are of the same magnitude as those reported in the watershed scale studies. However, caution should be exercised when drawing linkages between the plot and watershed scale studies, because the same response variables were not always measured and reported for all the cited studies. Additionally, due to hydrologic variability, the loadings measured from watershed scale golf course facilities are generally greater than those reported from plot scale studies. Cohen et al (*20*) emphasize the need for more comprehensive (concentrations and loadings) field-scale water quality studies on golf courses. The primary objective of the current research was to assess the impact that golf course management has on nutrient losses. This research was designed to address the following hypothesis: that nutrient discharge losses induced by turf management from a watershed scale recreational turf system (golf course) are not significant.

Methods

Experimental Site

The selected study site for this research effort was Northland Country Club (NCC), an historic country club and high quality, private golf course located in Duluth, MN. NCC has several subwatersheds 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 6 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 and grass. 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 located 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 16°C to 25°C (62°F to 77°F) while the average monthly maximum winter temperature (December-March) ranges from -9°C to 0°C (16°F to 32°F). Normal annual precipitation is 780 mm, 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 on the course are characteristic of lacustrine clay deposits, moderately deep (3 to 6 m) over bedrock. The Cuttre (very-fine, mixed, active, frigid Aeric Glossoaqualfs) and Ontonagon (very-fine, mixed Glossic Eutroboralfs) soils are the dominant soil series on this site with inclusions of the more poorly drained Bergland (very-fine, mixed, nonacid, frigid type Haplaquepts) series. Cuttre, Ontonagon, and Bergland soils have very similar morphological, chemical, and physical characteristics. Native vegetation associated with these soils was mixed hardwood, white spruce, and balsam fir forests. 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 on NCC (Table I) is characterized as moderate to intense. A regime of integrated management practices to control fertility, pests, irrigation and turf growth are used. These practices integrate mechanical, cultural, biological, and chemical practices designed to maintain high turf quality and limit the use of fertilizer and pesticides. NCC's integrated practices result in less dependence on chemical applications compared with many other local, private, and municipal golf courses (*22*).

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

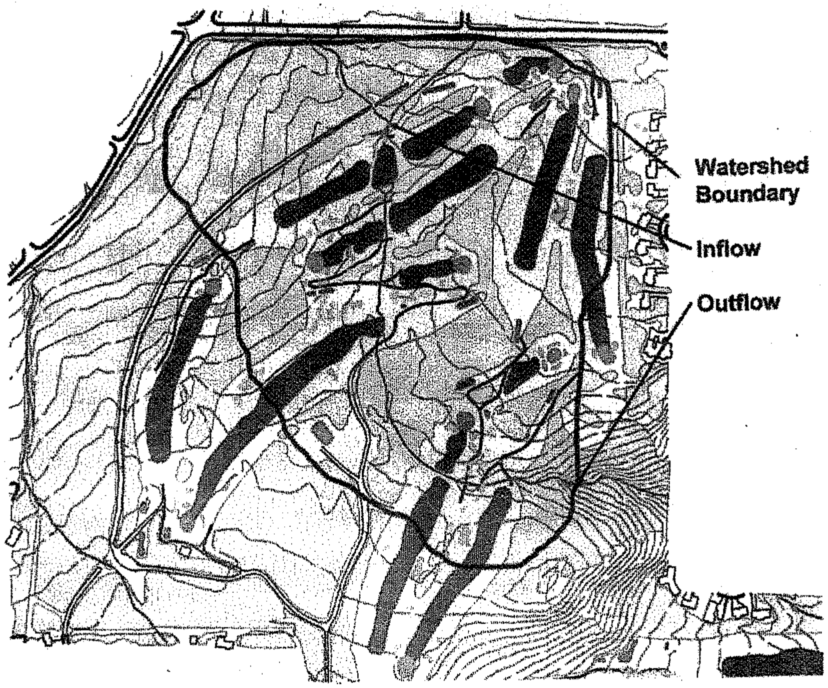

Figure 1. Layout of Northland Country Club Golf Course and study area. (See page 1 of color inserts.)

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 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 2004 ranged from three 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 were small, producing only minimal flows compared to the flows measured during the primary sampling period. Additionally, equipment limitations limited 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. During the primary sampling period, discharge and precipitation were recorded on ten minute intervals. Discrete water samples were collected using a flow proportional approach.

Table I. Management summary for NCC during the 2-year period (2003-2004)

Management Unit	*Grass*	*Fertilizer ($kg\ ha^{-1}\ yr^{-1}$)* *N*	*P*	*Irrigation ($mm\ yr^{-1}$)*
greens	creeping bentgrass	100	60	225
tees	creeping bentgrass	240	140	240
fairways	creeping bentgrass and Kentucky bluegrass	100	60	215
roughs	annual and Kentucky bluegrass	60	40	0

Following collection, all samples were handled according to United States Environments Protection Agency (USEPA) Method 353.3 for nitrogen analysis and USEPA Method 365.1 for phosphorus analysis (*23*). Samples were stored below 4 °C and analyzed within 28 days. Samples were vacuum filtered through a 0.45 μm 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 (*24*). Total nitrogen (TN) and total phosphorus (TP) analyses were performed in combination on unfiltered samples following alkaline persulfate oxidation (*25*), 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.

All statistical analyses were conducted with Minitab statistical software (*26*) and methods outlined by Haan (*27*). Normality was tested using the Kolmogorov and Smirnof test. Distributions were generally not normally distributed, thus median values were tested using the Mann-Whitney nonparametric statistic (α = 0.05).

Results and Discussion

Hydrology

Runoff occurs when the rate of precipitation is greater than the infiltration rate of the soil. 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 extraction and transport. The more intense the rainfall, the less time required to initiate storm runoff. Measured monthly precipitation during the study period was generally less than the long-term median amount recorded at the Duluth International Airport (Figure 2). Discharge volumes (combination of baseflow and storm event runoff) for the study period were equivalent to approximately 46% of the precipitation volume (Table II). The deep to moderately deep clayey soils on this course have some increased risk of surface runoff.

Nutrients

Periodic applications of nutrients are essential to maintaining high quality turf (*28*). Runoff losses of fertilizers are directly related to their timing and rate of application, formulation, chemical properties, and placement.

Table II. Measured Precipitation, Intensity, and Discharge for Upland Site, Upland Plus NCC and NCC during Data Collection Period April through November

			Upland		Upland + NCC		NCC	
Year (Apr-Nov)	*Rainfall (P) (mm)*	*Max. Int. (mm/hr)*	*Disch. (Q) (mm)*	*Q/P (%)*	*Disch. (Q) (mm)*	*Q/P (%)*	*Disch. (Q) (mm)*	*Q/P (%)*
2003	353	18.5	65	0.18	83	0.24	147	0.42
2004	482	21.1	118	0.24	143	0.30	235	0.49

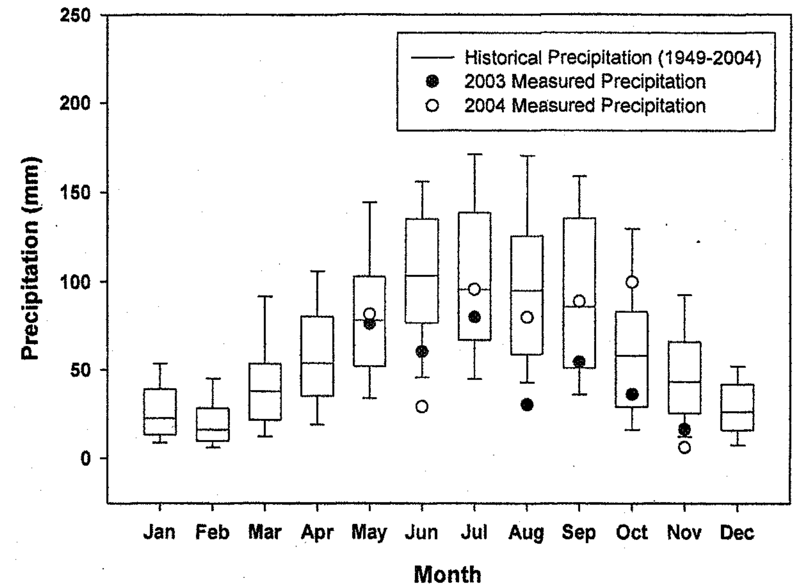

Figure 2. Historical (1949-2004) precipitation from the Duluth Airport (boxes are bound by 25th and 75th percentile values; line in the box represents the median; whiskers represent the 10th and 90th percentiles) and study period (2003-2004) measured precipitation at the experimental watershed site.

Concentrations

A range of nutrient concentrations were measured from the course (Tables III and IV). Median concentrations of NO_3-N were below 1 mg L^{-1}, and the maximum recorded concentrations were well below the USEPA drinking water standard of 10 mg L^{-1}. No statistical difference ($p > 0.05$) in median NO_3-N or NH_4-N concentration at the inflow and outflow sites was measured. This result suggests that the nitrogen fertilizer management regime used on this course does not contribute to significant increases in NO_3-N and NH_4-N in the stream. However, TN, DRP, and TP concentrations were significantly greater ($p < 0.05$) in the outflow compared to the inflow. The significant difference in TN concentration at the inflow and outflow is an indication of some organic nitrogen contribution from the course, most likely a result of tree litter decomposition and residue from the forested areas. The measured phosphorus concentrations were consistent with concentrations shown to cause eutrophic conditions in lakes, ponds, and streams (*29*). Increases in phosphorus concentration were generally noted with precipitation events.

Using the loads calculated for the course and the measured discharge, a concentration resulting from the course can be calculated. These resulting concentrations were 0.06 mg NH_4 L^{-1}, 0.31 mg NO_3 L^{-1}, 1.46 mg TN L^{-1}, 0.07 mg DRP L^{-1}, and 0.14 mg TP L^{-1}. These concentrations indicate that the course is adding some nutrients to the stream. The amounts of these additions are slightly greater than those resulting from the upland area.

Table III. Statistical Analysis[a] of Flow Proportional Nitrogen Concentrations (mg L^{-1}) in Surface Flow at NCC

	Surface flow concentration (mg L^{-1}) (n = 325 for inflow and n=508 for outflow)					
	NO_3		*NH_4*		*TN*	
	Inflow	*Outflow*	*Inflow*	*Outflow*	*Inflow*	*Outflow*
Mean	0.38	0.37	0.21	0.17	0.71	1.00
Median	0.25 a	0.26 a	0.02 a	0.03 a	0.62 a	1.01 b
Maximum	2.65	3.16	6.30	6.39	2.97	3.93

[a] Inflow and outflow medians by constituent were evaluated with the Mann-Whitney non-parametric test. Inflow and outflow medians for the same constituent followed by the same letter were not significantly different ($p < 0.05$).

Table IV. Statistical Analysis[a] of Flow Proportional Phosphorus Concentrations (mg L^{-1}) in Surface Flow at NCC

	Surface flow concentration (mg L^{-1}) (n = 325 for inflow and n=508 for outflow)			
	DRP		*TP*	
	Inflow	*Outflow*	*Inflow*	*Outflow*
Mean	0.05	0.09	0.08	0.10
Median	0.01 a	0.04 b	0.09 a	0.10 b
Maximum	2.42	2.59	0.23	0.55

[a] Inflow and outflow medians by constituent were evaluated with the Mann-Whitney non-parametric test. Inflow and outflow medians for the same constituent followed by the same letter were not significantly different ($p < 0.05$).

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 (*30*), the accumulation of thatch and organic matter in the topsoil (*31, 32*), and use of integrated best management practices also reduce the risk of nutrient losses (*33, 34, 35*).

Loads

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 was calculated by multiplying the analyte concentration by the measured water volume for that respective sample and summing over the study duration. The volume of water associated with any one sample was determined using the midpoint approach; the midpoint between each sample was determined and the volume of water calculated for that duration. The analyte concentration was assumed to be representative over that specific flow duration. Nutrient load attributed to the course was 0.11 kg ha^{-1} yr^{-1} NH_4-N, 0.59 kg ha^{-1} yr^{-1} NO_3-N, 0.14 kg ha^{-1} yr^{-1} DRP, 2.79 kg ha^{-1} yr^{-1} TN, and 0.27 kg ha^{-1} yr^{-1} TP. The loadings from this golf course are generally greater than or similar to loadings reported for native prairies (*36*) and forested catchments (*15, 37*), but less than loadings reported for agriculture (*38, 39*), the exception being phosphorus (Table V). Despite the relative immobility of phosphorus in soil (*33*), the results of this study suggest that this course may have the potential for small but significant contributions of phosphorus to surface water. This course has a long history of phosphorus applications. Once the soils become saturated with precipitated phosphorus, any additional phosphorus is more readily available for loss in surface runoff (*42*).

Summary and Conclusions

1. Surface water hydrology and nutrient concentrations were measured for 2.5 years at NCC.
2. A range of nutrient concentrations were detected in the surface water.
3. The nitrogen fertilization regime used on this course appears to pose little risk for significant inorganic nitrogen transport in surface runoff.
4. 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.
5. 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.

Acknowledgements

The authors would like to express their gratification to Sara Beth Scadlock, Ivy Leland, and Emily Burgess for aiding in site development and design as well

Table V. Nutrient loads (kg ha^{-1} yr^{-1}) from NCC and Other Selected Land Uses

Reference	*Land use*	*Area*	NH_4	NO_3	*TN*	*DRP*	*TP*	*Dur.*	*Study Site*
(40)	Tifway bermudagrass	25.2 m^2	---	3.05	---	---	---	4-yrs	Griffin, GA
(10)	80% Kentucky bluegrass; 20% perennial ryegrass	37.2 m^2	0.35	0.90	---	0.12	---	18-mos	Ithaca, NY
(36)	Native prairie	89.6 m^2	0.14	0.12	0.84	0.02	0.11	5-yrs	Big Stone County, MN
(41)	golf green (bermudagrass)	0.025 ha	---	0.52	---	---	---	3-mos	College Station, TX
	golf frwy. (bermudagrass)	1.57 ha	---	0.96	---	---	---		
(16)	golf course: storm events	29 ha	---	2.1	---	0.3	---	13-mos	Austin, TX
	golf course: baseflow		---	4.3	---	0.05	---		
(17)	golf course	29 ha	---	4.0	---	0.66	---	5-yrs	Austin, TX
(15)	golf course	53 ha	1.7	3.7	13.5	1.6	3.04	2-yrs	Japan
	forest	23 ha	0.2	4.1	5.4	0.03	0.13		
(38)	95% agriculture; 5% urban	327 ha	0.34	20.4	---	0.28	1.13	1-yr	Fayette County, KY
	43% agriculture; 57% urban	506 ha	0.95	10.8	---	0.12	1.14		
	99% urban; 1% agriculture	226 ha	0.52	5.97	---	0.07	0.66		
(39)	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	0.11	0.59	2.79	0.14	0.27	2-yrs	Duluth, MN

as routine data collection of both hydrology and water quality samples. The authors would also like to acknowledge and sincerely thank Ms. Ann Kemble for her technical support with respect to sample preparation and to Mr. Eric Fischer for providing his analytical expertise to this research effort. Additionally, the authors would like to thank the members and staff of Northland Country Club for granting us permission to conduct this study on their course. Finally, we would like to thank the U.S. Golf Association Green Section for funding support provided toward this research.

References

1. National Golf Foundation. *Golf Facilities in the U.S*; National Golf Foundation: Jupiter, Florida, 2003.
2. Balogh, J.C.; Leslie, A.R.; Walker, W.J.; Kenna, M.P. Development of integrated management systems for turfgrass. In *Golf course management and construction: Environmental issues*. Balogh, J.C.; Walker, W.J., Ed. Lewis Publishers, Inc.: Ann Arbor, Michigan, 1992; pp 355-439.
3. Beard, J.B.; Green, R.L. *J. Environ. Qual.* **1994**, *23*, 452-460.
4. Kohler, E.A.; Poole, V.L.; Reicher, Z.J.; Turco, R.F. *Ecological Engineering*. **2004**, *23*, 285-298.
5. Shuman, L.M. *J. Environ. Qual.* **2002**, *31*, 1710-1715.
6. Peacock, C.H.; Smart, M.M.; Warren-Hicks, W. In *Proceedings of the EPA Watershed 96 Conference*. U.S. EPA: Washington, D.C. 1996; pp 335-338.
7. Smith, A.E.; Bridges, D.C. *Crop Sci.* **1996**, *36*, 1439-1445.
8. Pratt, P.F. *Council for Agricultural Science and Technology, Report No. 103*. 1985. Ames, Iowa, pp 1-62.
9. Balogh, J.C.; Walker, W.J. *Golf Course Management and Construction: Environmental Issues*; Lewis Publishers: Ann Arbor, Michigan, 1992.
10. Easton, Z.M.; Petrovic, A.M. *Golf Course Management*. **2005**, *73*(5), 109-113.
11. Gaudreau, J.E.; Veitor, D.M.; White, R.H.; Provin, T.L.; Munster, C.L. *J. Environ. Qual.* **2002**, *31*, 1316-1322.
12. Cole, J.T.; Baird, J.H.; Basta, N.T.; Huhnke, R.L.; Storm, D.E.; Johnson, G.V.; Payton, M.E.; Smolen, M.D.; Martin, D.L.; Cole, J.C. *J. Environ. Qual.* **1997**, *26*, 1589-1598.
13. Linde, D.T.; Watschke, T.L. *J. Environ. Qual.* **1997**, *26*, 1248-1254.
14. Morton, T.G.; Gold, A.J.; Sullivan, W.M. *J. Environ. Qual.* **1988**, *17*, 124-130.
15. Kunimatsu, T.; Sudo, M.; Kawachi, T. *Water Sci. Tech.* **1999**, *39*, 99-107.
16. King, K.W.; Harmel, R.D.; Torbert, H.A.; Balogh, J.C. *J. Am. Water Resour. Assoc.* **2001**, *37*, 629-640.
17. Winter, J.G.; Dillon, P.J. *Environ. Pollut.* **2005**, *133*, 243-253.