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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 225 projects at a cost of $25 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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Constructed Wetlands on Golf Courses Help Manage Runoff from the Course and Surrounding Areas

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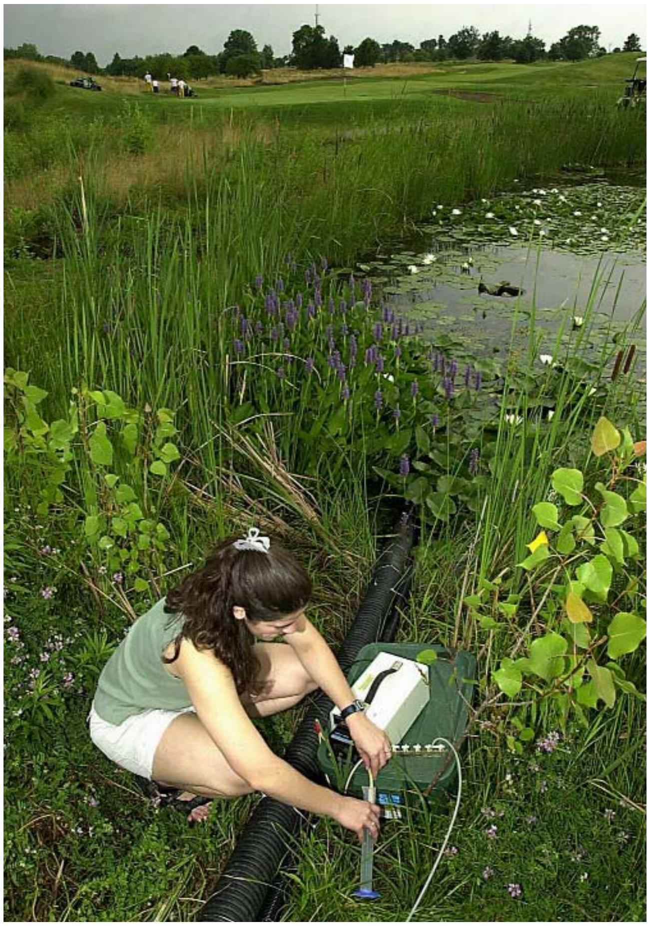
SUMMARY

This study conducted by Purdue University scientitists was initiated to determine the chemical characteristics of water moving through created wetlands associated with a commercial 18-hole golf course and a residential area, and track changes in water quality through the wetland system during storm and non-storm events. The study found:

- Even though 7,300 kg N was applied to the golf course area that drains into the wetland during the period when storm events were sampled, discharge of N-NO_3/NO_2 and N-NH_3 from the golf course tile was minimal (1.10 and 0.25 mg/L, respectively). The wetland efficiently removed an estimated 97% of N-NO_3/NO_2 and 100% of N-NH_3.
- Lower storm water concentrations for 13 of the 17 parameters (except K, Al, Mg, and Si) was found leaving the golf course than entering. Therefore, water exiting the golf course during storm events is not a major source of contamination to the Cuppy-McClure watershed despite urban runoff inputs and significant fertilizer and pesticide inputs used on the golf course.
- There was only one instance of pesticide detection during nonstorm events from any sampling location. During nonstorm events, only the dinitroaniline herbicide trifluralin was detected at 0.22 µg/L on September 28, 2001 and was found on the golf course at a site downstream of the first wetland. No trifluralin was applied to the golf course anytime during the study, so it is unknown how the chemical arrived on the golf course.
- Overall, our system demonstrated that created wetlands on golf courses can be used to effectivelyfilter golf course tile drains, as well as runoff from areas adjacent to the course.

Runoff from urban areas and golf courses is presumed to significantly contribute to nonpoint source (NPS) water pollution originating from urban areas. Generally, golf course drainage tile lines discharge to surface water systems whereas urban stormwater is managed using direct discharge to surface water or temporary storage in retention basins that eventually discharge to surface water.

To better define and possibly expand the role of golf courses in urban stormwater management, the 1998 renovation of Purdue University's North Golf Course incorporated a series of created wetlands that serve as both water hazards and water quality management tools. The wetland system was designed to allow golf course tile drainage and local urban surface drainage water to mix and be treated in a series of wetland cells, testing the hypothesis that sustainable water man-



Research at Purdue University demonstrates that golf course wetlands are an excellent way of reducing surface water pollution from nutrients, sediments, and many potential chemical pollutants.

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agement in the urban environment is possible using managed wetlands on a golf course as a treatment system.

The popularity of golf has led to the use of golf courses as a central part of many new home development projects. At the same time, these developing urban areas struggle with stormwater management because urbanization decreases the amount of permeable surface available for absorption and infiltration of rainwater and snow melt. This increased runoff can potentially contain urban pollution from roofs, roads, and parking lots (28) that is often carried directly to surface water.

Increasing stormwater runoff and velocity magnify problems of conveyance, increase storage volume required to reduce flooding, and raises the impact of potential contaminants such as oils, sediment, and heavy metals. Thus, stormwater management and cleanup have become increasingly important in urbanized areas, but are still largely based on the use of retention ponds.

Using created wetlands on golf courses as water-receiving locations offers a unique management and cleanup strategy for both the golf course and the urban stormwater that is better than the traditional stormwater retention basins. Golf courses are highly managed locations as the turfgrass receives nearly daily applications of irrigation water during the growing season. Even though best water management practices may be utilized, some of this water is passed to the drainage system and this water is ideal to maintain wet conditions for basal plant populations in the wetland cells.


Unlike stormwater retention basins, a wetland cell with active plants and anaerobic sediments will have a significant retention and degradation capacity for introduced materials.

Unlike stormwater retention basins, a wetland cell with active plants and anaerobic sediments will have a significant retention and degradation capacity for introduced materials. Created wetlands are able to remove significant amounts of suspended solids, organic matter, nutrients, heavy metals, trace elements, pesticides, and pathogens through chemical, physical, and biological processes (15). Natural and created wetlands have improved water quality of municipal wastewater (14), coal mine drainage (29), aquaculture wastewater (22, 35), and agricultural drainage (30, 21, 25).

While some data on the use of wetlands on golf operations is present in the literature (12, 23, 24), these data are variable among sites due to differing environmental conditions, hydrology, and vegetation (15), and were from limited-term studies. Wetlands also have several positive aesthetics characteristics such as increasing habitat for wildlife and flora while providing improved floodwater mitigation (4, 19, 20) for drainage and stormwater management. However, the most important aspect of wetlands is their ability to improve water quality.

This study was initiated to determine the chemical characteristics of water moving through created wetlands associated with a commercial 18-hole golf course and a residential area, and track changes in water quality through the wetland system during storm and nonstorm events. The site for our study was a newly-redesigned and renovated golf course called the Kampen Course on the campus of Purdue University. In re-designing the course, there was considerable concern about minimizing the inputs of potential, but unknown, golf-course-related non-point source pollution to Celery Bog, a highly valued park and recreation area adjacent to the new course. Additionally, with the planned re-design came the opportunity to address untreated runoff from the adjacent urban area that was previously tiled under the golf course directly into Celery Bog.

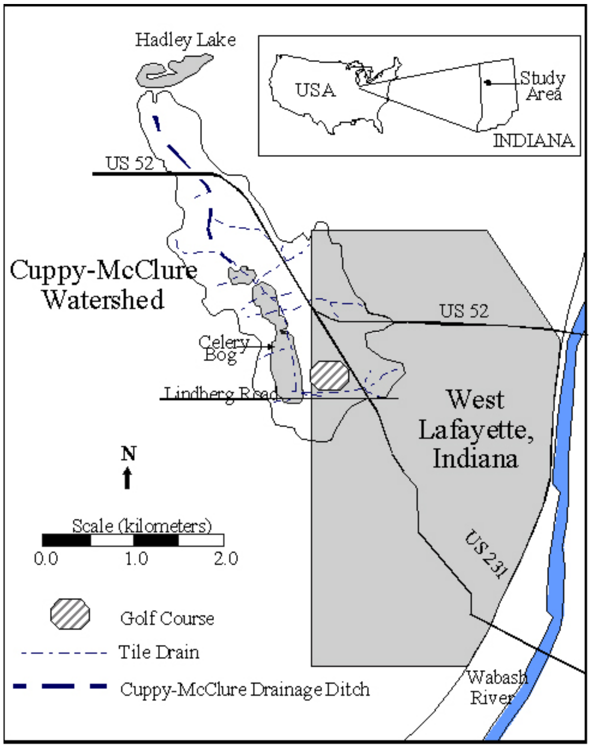

Figure 1. Location of Purdue University's Kampen golf course

Materials and Methods

Purdue University's Kampen Golf Course is part of the Birck Boilermaker Golf Complex located on the north edge of the City of West Lafayette, Indiana. The course is situated near the headwaters of the 392-hectare Cuppy-McClure watershed, a rapidly urbanizing area of West Lafayette (Figure 1). The golf course comprises 27.8 ha, of which 10.1 ha drain directly into the created wetlands used in this study. Following treatment in the wetland cells, the water either flows into the Celery Bog or is pumped back into irrigation ponds used on the course. The area adjacent to the northeast side of the golf course is urbanized and includes two residential highways, a motel and parking lot, gas station, and approximately 200 homes.

Initial construction of the re-designed course and wetlands was completed in early 1998, wetland plants were installed, and the course opened in June, 1998. The cells were mechanically cleared of all existing vegetation, packed, and re-vegetated with 10,800 plants that included (scientific name and number used), Arrowhead (*Sagittaria spp.*, 300), Banded Lake Sedge (*Carex lacustris*, 100), Burreed (*Sparganium americanum* , 200), Creeping Spikerush (*Eleocharis fallax Weatherby*, 100), Crested Sedge (*Carex cristatella*, 500), Harlequin Blueflag (*Iris versicolor* L., 500), Lake Sedge (*Carex lacustris* Willd., 500), Lurid Sedge (*Carex lurida*, 500), Pickerelweed (*Pontederia cordata* L., 750), Prairie Cordgrass (*Spartina pectinata* Bosc ex Link, 300), River Bulrush (*Scirpus fluviatilis* (Torrey) Gray, 250), Soft Rush (*Juncus effusus* L., 1500), Softstem Bulrush (*Schoenoplectus tabernaemontani* (K.C. Gmel.) Palla, 3100), Sweet Flag (*Acorus gramineus* Sol. ex Aiton grassleaf, 2000), Three Square Bulrush (*Scirpus pungens* Vahl,100), White Water Lilies (*Nymphaea alba*, 100), Woolgrass (*Scirpus cyperinus* (L.) Kunth, 200), and Yellow Pond Lilies (*Nuphar polysepalem*, 100).

Water flowing into the wetland system comes from a number of sources. During golf operations, April to November, water enters the wetland as part of the irrigation recovery system. Water also enters the wetlands as urban runoff from the adjacent areas. Urban runoff passes through a culvert under Northwestern Avenue (Site 1) then enters the golf course tile drainage (Figure 2). The mixed water then enters the constructed wetland's series of cells (Site 2) parallel to Lindberg Road. The first wetland cell is approximately 0.34 ha. The second wetland cell is approximately 0.37 ha. Outflow from the long-third cell (approximately 1.24 ha) into Celery Bog is limited to one point at the north end of the cell (Site 4). A drainage tile was also monitored in this effort (Site 3). However, it should be noted that numerous unmonitored tiles similar to Site 3 feed directly from the golf course into the long cell bordering Celery Bog. Water is also pumped from the south end of this long cell south and then east to the irrigation storage pond. The wetland cells contain water all year, but the constructed wetland will not discharge water to the adjacent natural system (site 4) except under high flow (storm) conditions. During the golf season, wetland water

Figure 2. Arial photo of Purdue University's Kampen golf course with numbers indicating water sampling sites.

is returned to the course from the irrigation pond using the irrigation system.

Four sites on the golf course and the watershed outlet were chosen for water sampling in this work (Figure 2). Sampling locations were selected to track the water as it progressed through the system, entered the eastern edge of the course, moved through the wetland system, and exited the northwestern edge of the course to Celery Bog or the south side to the irrigation pond. Site 1 (urban input or UI) characterizes urban runoff. Site 2 (after wetland one or AWO) characterizes water exiting the first wetland cell. Site 3 (golf course tile or GCT) characterizes golf course tile drainage just prior to entering the wetland system. Site 4 (golf course output or GCO) characterizes water exiting the constructed golf course wetlands and entering Celery Bog. Site 5 (watershed output or WO) is located at the mouth of the Cuppy-McClure watershed and characterizes the overall watershed water quality and provides a basis of comparison of water quality between the watershed and golf/urban discharge.

All golf course sampling sites were equipped with flow-control structures to measure flow, and automated water samplers to monitor water level, flow, rain, pH, temperature, conductivity, and dissolved oxygen on a 10- or 15-minute data storage interval during non-freezing weather. Additionally, samples were collected during the first flush of stormwater runoff shortly after a rain event began. This was done because it is thought that the highest concentration of potential pollutants is washed from surfaces and appears in the first flush of stormwater runoff.

Sampling dates were November 30, 1998, June 11, 1999, September 28, 1999, November 1, 1999, August 23, 2000, and November 6, 2000. First-flush grab samples taken during storm events were collected at each site and transported to Heritage Environmental Labs in Indianapolis for detailed chemical analysis. From April 2001 to August 2002, water sampling was conducted during base flow. Grab samples were collected at each site on April 19, 2001, June 19, 2001, September 28, 2001, December 19, 2001, June 25, 2002, and November 13, 2002 and analyzed at Heritage Environmental Labs.

All samples were analyzed for cations, anions, organophosphate pesticides, organochloride pesticides, and other potential contaminants such as nutrients, salts, metals, and petroleum products (Table 1). Base flow data compare the functioning of the wetland system under "normal" flow conditions. An estimate of the efficiency of the wetlands for reducing contaminants was calculated using mass flow levels by 100%-[GCO/(UI+GCT)]. This estimate only accounts for three monitoring sites and not all of the tile lines that drain into the system, thus this estimate was used only to provide a relative measure of wetland efficiency.

Results and Discussion

Storm Events

Urban input (UI) was the main source of N-NO_3/NO_2 and N-NH_3 (Table 2) into created wetland. Even though 7,300 kg N was applied to the golf course area that drains into the wetland during the period when storm events were sampled (Table 4), discharge of N-NO_3/NO_2 and N-NH_3 from the golf course tile was minimal (1.10 and 0.25 mg/L, respectively) (Table 2). The wetland efficiently removed N-NO_3/NO_2 and N-NH_3, removing an estimated 97% of N-NO_3/NO_2 and 100% of N-NH_3 (Table 5).

The area of the golf course that drains into the wetland received 922 kg P during the storm-event-sampling years (Table 4). Despite this, low levels (< 0.5 mg/L) of P were detected during storm events at all sites (Table 2). Mass loading removal of P was 74% during storm events (Table 5).

During storm events, K concentration in drainage water increased as water moved through the wetland (Table 2). Water at the GCO had a higher K concentration than water at either the GCT or the UI (Table 2) resulting in an overall mass removal efficiency of 12% (Table 5). This is similar to other work that found potassium concentration increases as water passes through a wetland (30) and that natural wetlands often export potassium (31).

Chemical oxygen demand (COD) and total organic carbon (TOC) were highest at the UI, which would be expected with the first flush of a storm pushing organic matter from a residential area (including roads and parking lots) into our created wetland system (26) (Table 2). However, COD and TOC were reduced by wetlands during storm events. Reductions from the UI to the GCO were 90% for COD and 91% for TOC (Table 5), which is similar to that found by Kao et al. (16) and Kao and Wu (18).

During storm events, GCT had the highest concentration of dissolved and suspended solids, while the UI had the lowest concentration (Table 2). Mass loading removal of dissolved solids was 59%, indicating that the wetlands were effective at removing dissolved solids during storm events (Table 5). However, mass loading removal of suspended solids was 0% in our study (Table 5), whereas other researchers found higher removal efficiencies of suspended solids during storm events (18, 25). This apparent difference could

Potential contaminants tested

2,4-D
2,4-DB
4,4'-DDD
4,4'-DDE
4,4'-DDT
2,4,5-TP
Aldrin
Alpha-BHC
Alpha-chlordane
Aluminum
Ammonia
Antimony
Arsenic
Atrazine
Barium
Benfluralin
Beryllium
Beta-BHC
Boron
Calcium
Chloride
Chloropyrifos
Chromium
Cobalt
Copper
Delta-BHC
Diazinon
Dicamba
Dieldrin
PCB aroclor 1016
Dissolved solids
PCB aroclor 1221
Endosulfan I
PCB aroclor 1232
Endosulfan II
PCB aroclor 1242
Endosulfan sulfate
PCB aroclor 1248
Endrin
PCB aroclor 1254
Endrin naldehyde
PCB aroclor 1260
Ethoprop
Pendimethalin
Fenarimol
Phosphorus
Gamma-BHC
Potassium
Gamma-chlordane
Prodiamine
Heptachlor
Selenium
Heptachlor epoxide
Silver
Iron
Silicon
Lead
Simazine
Lithium
Strontium
Magnesium
Sulfate
Manganese
Suspended solids
Malathion
Thallium
MCPA
Tin
MCPP
Titanium
Mercury
Total organic carbon
Methoxychlor
Toxaphene
Metolachlor
Triadimefon
Molybdenum
Trifluralin
Nickel
Vanadium
Nitrate/nitrite
Zinc
Oil and grease
Zirconium

Table 1. Water samples were analyzed for the presence of nutrients, metals, petroleum products, pesticides, and PCBs.

Parameter	Site[a]				
	UI	AWO	GCT	GCO	WO
	mg/L				
N-NO_3/NO_2	1.38	0.29	1.10	0.18	0.67
N-NH_3	2.70	0.42	0.25	0.30	0.60
P	0.31	0.11	0.44	0.44	0.45
K	3.35	5.43	5.80	6.41	2.77
Chemical O_2 demand	294	39	50	34	61
TOC	106.2	12.5	12.5	9.6	17.3
Dissolved solids	335	350	478	280	362
Suspended solids	33	47	155	92	228
Al	2.04	1.07	4.09	2.54	1.82
Ca	47.8	62.8	92.6	48.4	74.0
Cl	44.8	60.8	100.2	23.6	37.9
Fe	1.49	1.74	6.15	2.13	3.43
Mg	13.1	24.2	32.2	27.0	19.7
Mn	0.37	0.20	0.26	0.22	0.45
Na	20.8	28.8	42.4	8.1	19.8
Si	3.53	4.10	13.26	8.06	6.25
SO_4	26.7	38.7	70.8	50.6	62.3

[a] UI, urban input; AWO, after wetland one; GCT, golf course tile; GCO, golf course output; WO, watershed outlet. Data are averaged over six storm events.

Table 2. Mean concentration of nutrients and major elements in the wetland measured during six storm events

be due to the additional tile lines feeding water directly into the third long wetland cell bordering Celery Bog. The tile water came partially from sand bunkers on the golf course and tends to be high in suspended solids. We suggest there is little time or distance in the third cell during storm events to remove suspended solids before water passes into Celery Bog.

Both frequency and level of pesticide detection at any sampling location was low during storm events and no PCBs (poly-chlorinated biphenyls) were found. On June 11, 1999, atrazine was detected at 0.01 µg/L at UI and at 0.17 µg/L at AWO (Site 2), while simazine was detected at 0.22 µg/L at AWO. On November 1, 1999, MCPA at 0.56 µg/L was detected at AWO. No pesticides were detected during the four other sampling dates. None of the three pesticides detected were found at sites located on the golf course. The fact that atrazine was found at the UI, but not at GCO (Site 4), was likely due to the wetland removing atrazine as previous research has shown wetlands remove atrazine during storm events (17).

Work by Cohen et al. (9) suggests that simazine and especially atrazine are commonly detected during surface water quality studies on golf courses in the southern states, but these herbicides are not used on this golf course, or on turf in the northern areas of the country. Although the golf course was not treated with atrazine or simazine directly, these triazine herbicides are likely used in corn production areas that surround West Lafayette. Atrazine has been detected in rainwater (28, 32), so it is not surprising that it was detected both entering the golf course and in

Parameter	Site[a]				
	UI	AWO	GCT	GCO	WO
	mg/L				
$N\text{-}NO_3/NO_2$	0.68	0.36	0.85	0.4	0.45
$N\text{-}NH_3$	0.27	0.31	0.31	0.27	0.35
P	0.15	0.9	0.17	0.18	0.19
K	3.47	3.40	4.67	3.72	4.03
Chemical O_2 demand	37	43	19	35	39
TOC	9.6	7.9	4.3	9.8	12.5
Dissolved solids	520	462	697	330	492
Suspended solids	16	83	249	142	41
Al	0.28	1.78	3.21	2.75	2.41
Ca	89.2	80.3	132.0	47.8	85.0
Cl	130.2	75.0	138.5	33.8	49.7
Fe	0.75	2.88	2.27	2.03	2.38
Mg	23.5	28.0	54.0	25.0	22.0
Mn	0.41	0.43	0.47	0.22	0.25
Na	81.5	36.7	66.0	15.5	28.5
Si	4.78	6.20	11.13	6.00	7.62
SO_4	34.0	43.2	75.5	40.0	53.3

[a] UI, urban input; AWO, after wetland one; GCT, golf course tile; GCO, golf course output; WO, watershed outlet. Data are averaged over six nonstorm events.

Table 3. Mean concentration of nutrients and major elements in the wetland measured during six nonstorm events

the watershed. However, despite common use of 2,4-D and dicamba on homelawns for broadleaf weed control in turfgrass (13), no 2,4-D or dicamba was found during storm events at any site, including the UI.

No metals such as As, Cd, Cr, Cu, Pb, Hg, or Se were detected during storm events from any sampling location despite the urban area having roads and parking lots where heavy metals are likely to be found (15, 26, 28). Likewise, oil and grease were not detected during storm events at any sampling location, including the urban input with its close proximity to roads, a gas station, and parking lot, which potentially can be sources of petroleum product pollutants (28, 34).

The golf course's impact on wetland water quality can be summarized by comparing parameters at the UI and the GCO. During storm events, 11 of the 17 measured parameters (NO_3/NO_2, NH_3, P, COD, TOC, dissolved solids, Ca, Cl, Mg, Mn, and Na) had higher mass loading entering the course at the UI than leaving the golf course at the GCO (Table 5). Thus, during storm events the mass of most of the parameters decreased as water flowed through the wetland system. Furthermore, not all storm events (June 11, 1999 and August 23, 2000) were great enough to cause discharge from the largest wetland cell into Celery Bog, and causing all water and any potential contaminants to remain within the closed wetland system.

Comparing data at GCO with data from the whole watershed outlet (WO) provides an estimate of the impact of the golf course within the entire watershed. A lower concentration for 13 of

Years	Nutrient										
	N	P	K	S	B	Cu	Fe	Mg	Mn	Mo	Zn
	kg										
Storm											
1998 - 2000	7304	922	4582	1271	1.9	4.9	349	0.7	5.2	0.1	4.8
Nonstorm											
2001 - 2002	2628	205	1438	458	0.3	0.9	152	1.5	1.5	0.0	0.8

Table 4. Amounts of nutrient materials applied to the 10.1-hectare area of the golf course that drains into the created wetlands based on golf course fertilizer application records during storm event and nonstorm event sampling years

the 17 parameters (except K, Al, Mg, and Si) was found at the GCO than at WO (Table 2). Therefore, water exiting the golf course during storm events is not a major source of contamination to the Cuppy-McClure watershed despite urban runoff inputs and significant fertilizer and pesticide inputs used on the golf course.

As for the exceptions, golf course fertilization is unlikely responsible for the export of Al, Mg, or Si from the golf course, but may be the result of erosion or leaching through sand bunkers. Conversely, 922 kg K was applied to the golf course and may have added to the K export. However, previous research has shown wetlands often export K which may have also increased K levels in the system (30, 31).

Nonstorm Events

Concentration of N-NO_3/NO_2 and N-NH_3 discharged from the GCT (Site 3) was minimal (< 1.0 mg/L for N-NO_3/NO_2 and < 0.5 mg/L for N-NH_3). The wetlands reduced the N-NO_3/NO_2 concentration by as much as 95%. In contrast to N-NO_3/NO_2, there was little change in N-NH_3 concentration through the wetlands suggesting denitrification was likely responsible for N-NO_3/NO_2 reductions. It is reassuring to note that while the golf course applied 2,628 kg N to the area that drains into the wetland during the period when nonstorm events were sampled (Table 4), the average level of N-NO_3/NO_2 and N-NH_3 in the GCT were only 0.85 and 0.31 mg/L, respectively (Table 3).

Previous research on other golf course water features found low levels (< 2 mg/L) of N-NO_3/NO_2 or N-NH_3 despite aggressive fertilization (23, 24). Other research on a golf course showed significant increases in nitrate and ammonium in a wetland system, which the authors concluded was due to golf course fertilization (24). However, after moving through that wetland system, the nutrient concentrations were extremely low (< 1 mg/L) (24), which concurred with our study.

Also, it should be noted that this golf course pumps water from the third long wetland cell into a storage pond and then recycles it to the irrigation system. This irrigation water is applied to the course and drains back into the wetland for additional treatment where it is either redirected to the irrigation pond or to Celery Bog. This system of treating irrigation return flow is ideal for nitrate removal (2). Our data suggest there is no buildup of N levels in the wetland due to the recirculation of irrigation water as N levels detected at all sites on the course were < 1 mg/L N-NO_3/NO_2/NH_3 even with fertilizer applications.

Low levels (< 0.5 mg/L) of P were detected during nonstorm events (Table 3) despite that the area of the golf course that drained into the wetlands during nonstorm-sampling years was fertilized with 205 kg P (Table 4). However, the GCT contributed higher amounts of P that were not reduced before reaching the GCO. Despite higher P concentrations at the GCO than at the UI, concentrations were < 1 mg/L at all sites (Table 3). Thus, our results are in agreement with Brix (4) that most created wetlands are able to remove P from water with most wetlands producing effluents with < 1 mg/L total P. Overall, low (< 0.07 mg/L) levels of phosphorus have been found in golf course wetlands (23, 24), and our findings are in agreement.

The golf course was not a major source of K, nor was the constructed wetland a sink for K (Table 3). While there was a slight reduction in K concentration between the GCT and GCO, K concentration remained unchanged as water passed through the wetland system during nonstorm events (Table 3). Other researchers have found an increase in K as water passes through a wetland (30), and Richardson (31) concludes that natural wetlands often export K.

Trends in chemical oxygen demand (COD) were similar to the results for total organic carbon (TOC) trends (Table 3). COD and TOC levels were stable as water flowed through the

Parameter	**Site**[a]				**Relative reduction**[b]
	UI	AWO	GCT	GCO	
Flow	L/s				
	8.68	8.1	0.97	4.18	
Load					
	mg/s				%
$N\text{-}NO_3/NO_2$	8.15	3.20	1.18	0.25	97
N-NH3	17.94	3.41	0.28	0.00	100
P	2.08	1.24	0.69	0.71	74
K	28.0	30.8	9.0	32.6	12
Chemical O_2	1465	330	54	154	90
TOC	473	91	11	42	91
Dissolved solids	2386	1969	354	1128	59
Suspended solids	173	339	256	1212	0
Al	10.5	5.5	8.1	24.2	0
Ca	376	358	93	254	46
Cl	352	287	46	92	77
Fe	9.2	9.4	12.9	19.6	11
Mg	102	120	28	100	23
Mn	1.40	1.38	0.41	0.88	51
Na	172	129	19	28	85
Si	34	32	18	59	0
SO_4	188	189	74	230	12

[a] UI, urban input; AWO, after wetland one; GCT, golf course tile; GCO, golf course output. Data are averaged over six storm events.

[b] Relative reduction in load of (UI + GCT) upon leaving GCO as calculated by 100%-[GCO/(UI+GCT)].

Table 5. Mass flow of nutrients and major elements in the wetland measured during the first 15-minute interval when a rise in water level triggered water sampling during storm events.

constructed wetland system. The GCT had lower COD and TOC than the UI which would be expected due to soil filtering water before entering the tile lines (7, 11). However, COD and TOC at GCO increased to near UI levels (Table 3). Other researchers have found a 77% decrease in COD (7) and a 535% increase in TOC (30) as water passes through a wetland.

Passage though the wetlands reduced dissolved solids concentration by as much as 53% (Table 3). This is in contrast to Kadlec and Knight (15) who report that dissolved solids generally are not affected by wetlands. In contrast to our findings with dissolved solids, the wetland had little effect on suspended solids concentration during nonstorm events. The UI had the lowest suspended solid concentration while the GCT had the highest suspended solid concentration (Table 3).

Parameter	**Site**[a]				**Relative reduction**[b]
	UI	AWO	GCT	GCO	
Flow	--------------------------L/s------------------------------				
	0.48	0.82	0.27	0	
Load					
	-------------------------mg/s----------------------------				%
$N\text{-}NO_3/NO_2$	0.30	0.42	0.35	0	100
N-NH3	0.10	0.38	0.05	0	100
P	0.04	0.10	0.09	0	100
K	1.28	3.54	1.63	0	100
Chemical O_2	13.7	62.3	7.8	0	100
TOC	0.73	4.72	1.19	0	100
Dissolved solids	235	358	237	0	100
Suspended solids	2.4	187.3	16.6	0	100
Al	0.11	3.88	0.23	0	100
Ca	43.3	77.7	43.6	0	100
Cl	59.7	56.6	45.0	0	100
Fe	0.22	5.42	0.37	0	100
Mg	11.2	24.9	17.4	0	100
Mn	0.10	0.41	0.22	0	100
Na	36.0	28.7	22.3	0	100
Si	2.12	10.18	3.43	0	100
SO_4	15.3	35.4	29.6	0	100

[a] UI, urban input; AWO, after wetland one; GCT, golf course tile; GCO, golf course output. Data are averaged over six storm events.

[b] Relative reduction in load is 100% for all parameters due to no flow off the golf course at GCO during baseline flow conditions.

Table 6. Mass flow of nutrients and major elements in the wetland during nonstorm events based on measurements during water sampling

This may be due to the fact that water entering the urban area passes through a grassy ditch prior to reaching the UI, given that vegetative filters are important in total suspended solids removal (33). The GCT water has no such type of bio-filter as much of this water enters the tile lines directly from erodable sand bunkers. Between the UI and the GCO suspended solids were not altered during nonstorm events. This is in contrast with other researchers' reports that created wetlands are able to remove suspended solids from water (4, 14, 15, 27, 33, 37). It is unknown why the wetlands in our study did not have an impact on suspended solids during nonstorm events.

There was only one instance of pesticide detection during nonstorm events from any sampling location. During nonstorm events, only the dinitroaniline herbicide trifluralin was detected at 0.22 µg/L on 28 Sept. 2001 and was found on the golf course at AWO. No trifluralin was applied to the golf course anytime during the study, so it is unknown how the chemical arrived on the golf course. It is not surprising that so few pesticides were detected in the wetland system because previous research has shown created wetlands are able to reduce pesticide concentrations (3, 18, 25). Furthermore, all the wetland cells are surrounded by turf, and any pesticides would have been applied directly to the turfgrass. Previous research on the leaching and runoff of pesticides applied to turfgrass has shown minimal loss (10). Thus, vegetative strips such as those that surround the wetland cells (and drainage ditch prior to the UI) are effective filters for chemicals in surface runoff (1, 8). This may explain why no 2,4-D or dicamaba was detected at any site, including the UI, despite the common use of 2,4-D and dicamba on homelawns for broadleaf weed control (13).

The heavy metals As, Cd, Cr, Cu, Pb, Hg, or Si were not detected during nonstorm events from any sampling location despite the urban area having roads and parking lots where heavy metals are likely to be found (15, 26, 28). Likewise, oil and grease were not detect during nonstorm events at any sampling location, including the UI with its close proximity to roads, a gas station, and parking lot, which can potentially be a source of petroleum-based pollutants (28, 34). The lack of heavy metals and petroleum products at the UI may again be due to the water passing through a grassy ditch prior to reaching UI because vegetative buffers reduce heavy metal concentration in runoff (8).


The created wetland system in the study at Purdue University was efficient at improving water quality.

Comparing measured parameters at the UI and the GCO can estimate the golf course's impact on wetland water quality. During nonstorm events, only seven of the 17 measured parameters (NO_3/NO_2, COD, dissolved solids, Ca, Cl, Mg, and Na) had a higher concentration in water at the UI than at GCO (Table 3). Thus, during nonstorm events, the concentrations of eight of the different parameters increased as water flowed through the wetland system. However, the concentrations of these parameters was well below drinking water standards and no discharge occurred at the GCO into Celery Bog. Thus, despite increasing concentration of eight of the 17 parameters, all water was contained within the closed-looped wetland system, resulting in 100% mass removal efficiencies for all parameters (Table 5).

Although there was an increase in concentration for most parameters during flow through the golf course wetlands during nonstorm events, 14 of the 17 parameters (except suspended solids, Al, and Mg) were at a lower concentration at GCO than at WO (Table 3). Therefore, water on the golf course does not represent a major source of pollutants to the Cuppy-McClure watershed. This is in spite of the significant fertilizer and pesticide inputs used on the course, as well as the wetland's processing of urban runoff. As for the exceptions, golf course fertilizer practices are unlikely to be the reason for the net increase of Al and Mg across the wetland since no Al and only 1.5 kg Mg were applied during nonstorm event sampling years to the 10.1-h area of the golf course that drained into the created wetlands.

Our study showed that this golf course does not reduce quality of its water compared to water entering the golf course or water in the larger Cuppy-McClure watershed. The created wetland system in our study was efficient at improving water quality. Although mass removal efficiency ranged from -182% to 100% during storm events, 9 of 17 parameters had mass removal efficiencies >50% as water flowed through the wetland system. More importantly, mass removal efficiencies were 100% during baseline flow conditions due to no flow off the course. Therefore, with the combination of higher mass removal efficiencies and the lack of flow into Celery Bog during nonstorm events, introduction of potential pollutants into the greater watershed is highly unlikely during normal, day-to-day operation of the golf course wetland.

Overall, our system demonstrated that created wetlands on golf courses can be used to filter golf course tile drains, as well as runoff from areas adjacent to the course. With the increasing number of golf courses in urbanized areas, created wetlands could be used to improve regional water quality while enhancing the aesthetics of golf courses. However, to insure maximum water quality improvement, wetlands should be sized to maximize water holding during storm events and to minimize outputs during nonstorm periods.

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