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Managing Runoff with Constructed Wetlands

Purdue University research demonstrates how constructed wetlands can be used to limit runoff.

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Runoff from urban areas and golf courses is automatically presumed to contribute significantly to non-point (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 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 management in the urban environment is possible using managed wetlands on a golf course as a treatment system.

GOLF AND COMMUNITY DEVELOPMENT

The popularity of golf has led to the use of golf courses as centerpieces for 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 snowmelt. This increased runoff can potentially contain urban pollution from roofs, roads, and parking lots that is often carried directly to surface water. Increasing stormwater runoff and velocity magnifies problems of moving water from one area to another, increases 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 these efforts 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. Golf courses are highly managed locations, and the turfgrass receives regular 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 for maintaining 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. 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. In other settings, natural and created wetlands have improved the quality of the water emanating from municipal sources, coal mine drainage, aquaculture, and agricultural drainage.

Unlike stormwater retention basins, a wetland cell with active plants and anaerobic sediments will have a significant retention and degradation capacity for introduced materials. The created wetland system in the Purdue University research study was efficient at improving water quality.

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

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

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 non-storm events. The site for our study was the newly redesigned and renovated Kampen Course on the campus of Purdue University. In redesigning the course, there was considerable emphasis on minimizing the inputs of potential, but unknown, golf-course-related non-point source pollution to Celery Bog, a highly valued park and recreational area adjacent to the new course. Additionally, with the planned redesign came the opportunity to address untreated runoff from the adjacent urban area that was previously tiled under the golf course directly into Celery Bog.

MATERIALS AND METHODS

Purdue University's Kampen Golf Course is part of the Birck Boilermaker Golf Complex located in West Lafayette, Indiana. The course is situated near the headwaters of the 968-acre Cuppy-McClure watershed, a rapidly urbanizing area of West Lafayette. The golf course comprises 69 acres, of which 25 acres drain directly into the created wetlands used in this five-year study. Following treatment in the wetland cells, the water either flows into 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 redesigned 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):

1. Arrowhead (*Sagittaria spp.*, 300)
2. Banded lake sedge (*Carex lacustris,* 100)
3. Burreed (*Sparganium americanum,* 200)
4. Creeping spikerush (*Eleocharis fallax* Weatherby, 100)
5. Crested sedge (*Carex cristatella,* 500)
6. Harlequin blueflag (*Iris versicolor* L., 500)
7. Lake sedge (*Carex lacustris* Willd., 500)
8. Lurid sedge (*Carex lurida,* 500)
9. Pickerelweed (*Pontederia cordata* L., 750)
10. Prairie cordgrass (*Spartina pectinata* Bosc ex Link, 300)
11. River bulrush (*Scirpus fluviatilis* [Torrey] Gray, 250)
12. Soft rush (*Juncus effusus* L. 1,500)
13. Softstem bulrush (*Schoenoplectus tabernaemontani* [K. C. Gmel.] Palla, 3,100)
14. Sweet flag (*Acorus gramineus* Sol. ex Aiton grassleaf, 2,000)
15. Three square bulrush (*Scirpus pungens* Vahl, 100)
16. White water lilies (*Nymphaea alba,* 100)
17. Woolgrass (*Scirpus cyperinus* (L.) Kunth, 200)
18. 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. The mixed water then enters the constructed wetland's series of cells. The wetland cells contain water all year, but the constructed wetland will not discharge water to the adjacent natural system except under high flow (storm) conditions. During the golf season, wetland water is returned to the course from the irrigation pond using the irrigation system.

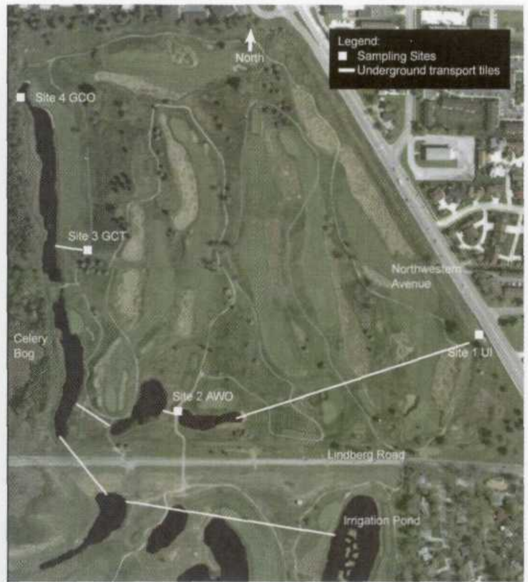
Four sites on the golf course and the watershed outlet were chosen for water sampling in this work. Sampling locations were selected to track the water as it progressed through the system, entered the eastern edge of the course, moved through the wetland system, and exited the northwestern edge of the 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.

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 the created wetland. Even though more than 16,000 lbs. of N was applied to the golf course area that drains into the wetland (25 acres) during the five-year 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 ppm, respectively) (Table 2). The wetland efficiently removed an estimated 97% of $N-NO_3/NO_2$ and 100% of $N-NH_3$.

The area of the golf course that drains into the wetland received 2,033 lb. P during the five-year storm-event sampling years. Despite this, low levels (<0.5 ppm) of P were detected during storm events at all sites (Table 2). Mass loading removal of P was 74% during storm events.

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),



Aerial photo of Purdue University's Kampen Golf Course with numbers indicating water sampling sites.

resulting in an overall mass removal efficiency of 12%. This is similar to other work that found potassium concentration increases as water passes through a wetland and that natural wetlands often export potassium.

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 the created wetland system (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.

During storm events, GCT had the highest concentration of dissolved and suspended solids, while the UI had the lowest concentration. Mass loading removal of dissolved solids was 59%, indicating that the wetlands were effective at removing dissolved solids during storm events. However, mass loading removal of suspended solids was 0% in this study. Other researchers found higher removal efficiencies of suspended solids during storm events. This apparent difference could be due to the additional tile lines feeding water directly into the third long wetland cell border-

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

Parameter	Site*				
	UI	AWO	GCT	GCO	WO
			ppm		
$N-NO_3/NO_2$	1.38	0.29	1.10	0.18	0.67
$N-NH_3$	2.70	0.42	0.25	0.30	0.60
Phosphorus (P)	0.31	0.11	0.44	0.44	0.45
Potassium (K)	3.35	5.43	5.80	6.41	2.77
Chemical O_2 demand	294	39	50	34	61
Total Organic Carbon (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
Aluminum (Al)	2.04	1.07	4.09	2.54	1.82
Calcium (Ca)	47.83	62.83	92.60	48.40	74.00
Chlorine (Cl)	44.77	60.83	100.20	23.60	37.85
Iron (Fe)	1.49	1.74	6.15	2.13	3.43
Magnesium (Mg)	13.13	24.17	32.20	27.00	19.67
Manganese (Mn)	0.37	0.20	0.26	0.22±	0.45
Sodium (Na)	20.75	28.83	42.40	8.14	19.77
Silicon (Si)	3.53	4.10	13.26	8.06	6.25
SO_4	26.67	38.67	70.80	50.60	62.33

*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.

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.

ing Celery Bog. The tile water came partially from sand bunkers on the golf course and tends to be high in suspended solids.

Both frequency and level of pesticide detection at any sampling location were low during storm events, and no PCBs (poly-chlorinated biphenyls) were found. On June 11, 1999, atrazine was detected at 0.01 ppb at UI and at 0.17 ppb at AWO (Site 2), while simazine was detected at 0.22 ppb at AWO. On November 1, 1999, MCPA at 0.56 ppb was detected at AWO. No pesticides were detected on 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 that wetlands remove atrazine during storm events. 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, so it is not surprising that it was detected both entering the golf course and in the watershed. Despite common use of 2,4-D and dicamba on home lawns for broadleaf weed control in turfgrass, however, no 2,4-D or dicamba was found during storm events at any site, including the UI.

No metals such as arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), or selenium (Se) were detected during storm events at any sampling location, despite the urban area having roads and parking lots where heavy metals are likely to be found. 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.

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. 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, 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 the 17 parameters, except potassium (K), aluminum (Al), magnesium (Mg), and silicon (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 not likely 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, 2,033 lb. K was applied to the 25-acre golf course area over five years and may have added to the K export. However, previous research has shown that wetlands often export K, which may also have increased K levels in the system.

NON-STORM EVENTS

Concentration of N-NO_3/NO_2 and N-NH_3 discharged from the GCT

(Site 3) was minimal (<1.0 ppm for N-NO_3/NO_2 and <0.5 ppm 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 that denitrification was likely responsible for N-NO_3/NO_2 reductions. It is reassuring to note that while the golf course applied 5,800 lb. N to the area that drains into the wetland during the five-year period when non-storm events were sampled, the average levels of N-NO_3/NO_2 and N-NH_3 in the GCT were only 0.85 and 0.31 ppm, respectively (Table 3).

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. 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 ppm N-NO_3/NO_2/NH_3, even with fertilizer applications.

Low levels (<0.5 ppm) of P were detected during non-storm events (Table 3), even though the area of the golf course that drains into the wetlands during non-storm sampling years was fertilized with 450 lb. P. 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 ppm at all sites (Table 3). Our results show that these created wetlands were able to remove P from water effluents with <1 ppm total P.

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 non-storm events (Table 3). Other researchers have also found an increase in K as water passes through a wetland.

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 constructed wetland system. The GCT had lower COD and TOC than the UI, which would be expected due to soil filtering the water before entering the tile lines. However, COD and TOC at GCO increased to near UI levels (Table 3).

Passage through the wetlands reduced the concentration of dissolved solids by as much as 53% (Table 3). The UI had the lowest suspended solid concentration, while the GCT had the highest suspended solid concentration (Table 3). This may be due to the fact that water entering the urban area passes through a grassy ditch prior to reaching the UI, and previous research clearly shows that vegetative filters are important in removing suspended solids. The GCT water has no such type of bio-filter, as much of this water enters the tile lines directly from erodable sand bunkers.

There was only one instance of pesticide detection during non-storm events from any sampling location. During non-storm events, only the dinitroaniline herbicide trifluralin was detected at 0.22 ppb on September 28, 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. 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. Thus, vegetative strips

Table 3

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

Parameter	Site* UI	AWO	GCT	GCO	WO
			ppm		
N-NO_3/NO_2	0.68	0.36	0.85	0.04	0.45
N-NH_3	0.27	0.31	0.31	0.27	0.35
P	0.15	0.09	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	89.17	80.33	132.00	47.80	85.00
Cl	130.17	75.00	138.50	33	49.67
Fe	0.75	2.88	2.27	2.03	2.38
Mg	23.50	28.00	54.0	25.00	22.00
Mn	0.41	0.43	0.47	0.22	0.25
Na	81.50	36.67	66.00	15.47	28.50
Si	4.78	6.20	11.13	6.00	7.62
SO_4	34.00	43.17	75.50	40.00	53.33

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

The Kampen Course on the Purdue University campus was the site used to investigate wetland filtering capabilities. The study determined the chemical characteristics of water moving through created wetlands associated with an 18-hole golf course and a residential area.

such as those that surround the wetland cells (and drainage ditch prior to the UI) are effective filters for chemicals in surface runoff. This may explain why no 2,4-D or dicamba was detected at any site, including the UI, despite the common use of 2,4-D and dicamba on home lawns for broadleaf weed control.

The heavy metals As, Cd, Cr, Cu, Pb, Hg, or Si were not detected during non-storm events from any sampling location despite the urban area having roads and parking lots where heavy metals are likely to be found. Likewise, oil and grease were not detected during non-storm 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.

Comparing measured parameters at the UI and the GCO can estimate the golf course's impact on wetland water quality. During non-storm 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 non-storm 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. Although there was an increase in concentration for most parameters during flow through the golf course wetlands during non-storm 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.

BOTTOM LINE: CREATED WETLANDS WORK

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 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 non-storm events, introduction of potential pollutants into the greater watershed is highly unlikely during normal, day-to-day operation of the golf course wetland.

Overall, this 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 sufficiently to maximize water-holding during storm events and to minimize outputs during non-storm periods.

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Editor's Note: For a full-text version of this report, including nutrient and chemical mass loadings, use URL http://usgatero.msu.edu/v04/n02.pdf of USGA Turfgrass and Environmental Research Online (http://usgatero.msu.edu).

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