TURFGRASS AND ENVIRONMENTAL RESEARCH ONLINE

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Laboratory and field studies were initiated to investigate *in situ* methods for filtering pollutants from drainage waters. The filter materials including a media blend of granualr activated carbon, clinoptilolite, and activated alumina, as well as blast furnace slag, cement kiln dust, coconut shell activated carbon, clinoptilolite, and sand, were effective for reducing phosphorus and select pesticides including chlorothalonil, metalaxyl, propiconazole, and mefenoxam, under low-flow conditions. They were not effective at removing nitrogen, however.

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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 1921, the USGA has funded more than $40 million for research at universities. 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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Addressing Subsurface Nutrient and Pesticide Loss Through End-of-Tile Filters

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SUMMARY

Laboratory and field studies were initiated to investigate *in situ* methods for filtering pollutants from drainage waters. Based on the laboratory and field results for the filter materials tested:

- Effectiveness of the material was better in low flow or baseflow conditions compared to storm flow.
- Detention time during storm flow is too short for adequate treatment or removal of pollutant.
- The amount of filter material needs to be increased or the delivery design improved for maximum effectiveness.
- The filter materials are not effective for nitrogen.
- The filter materials evaluated were effective for reducing phosphorus and select pesticides.
- Identification and demonstration of filter technologies offer superintendents a scientifically based option to better manage drainage waters in problem or environmentally sensitive areas.

Subsurface tile drainage is critical for the playability of managed, recreational turfgrass including golf courses and athletic playing fields. Tile drainage is primarily designed to rapidly convey water from a site, especially in the case of a storm event. Drainage networks rapidly, efficiently, and economically remove excess water from a site, thus permitting traffic. However, the environmental impacts attributed to subsurface drainage are of concern. Identifying, testing, and implementing practices or strategies that reduce the environmental impacts of subsurface drainage are required to maintain a balance of productivity and environmental protection.

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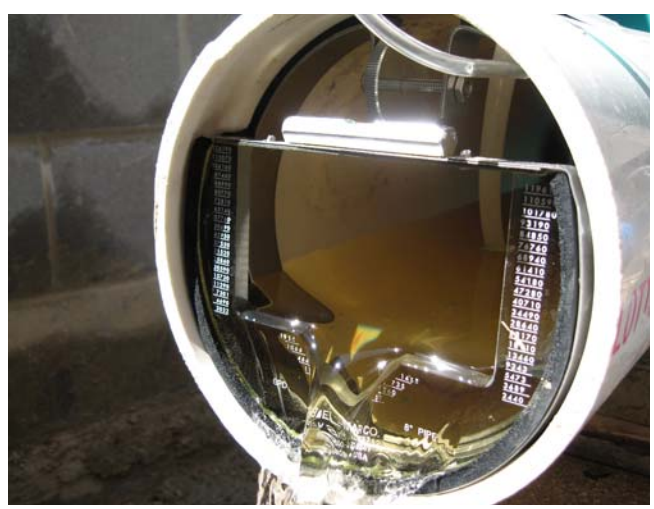
Discharge from subsurface tile drains is known to carry elevated levels of dissolved pollutants such as phosphorus (5), nitrogen (3), and pesticides (4). Moreover, subsurface drainage that conveys discharge directly into streams and ponds bypasses natural and managed filter processes. As a consequence, excess NO_3-N discharged into the Mississippi River has led to a growing hypoxic area downstream in the Gulf of Mexico (2). Similarly, phosphorus originating from upper Midwest tile-drained lands is a significant driver of eutrophication and hypoxia in the Great Lakes (9). Additionally, excess phosphorus levels detected in water features in or surrounding managed turf sites have led to eutrophic conditions in those water bodies (7, 12). Furthermore, pesticides have been detected in tile drainage waters and have been implicated in the decline of amphibian pouplations (10).

Agronomic practices alone such as application timing, placement, and rate have not appreciably reduced the pollutant transport from tile drained watersheds (3). Thus, remediation efforts have shifted more towards in-place physical and



Compound weir insert used to measure the amount of water discharged from a tile.

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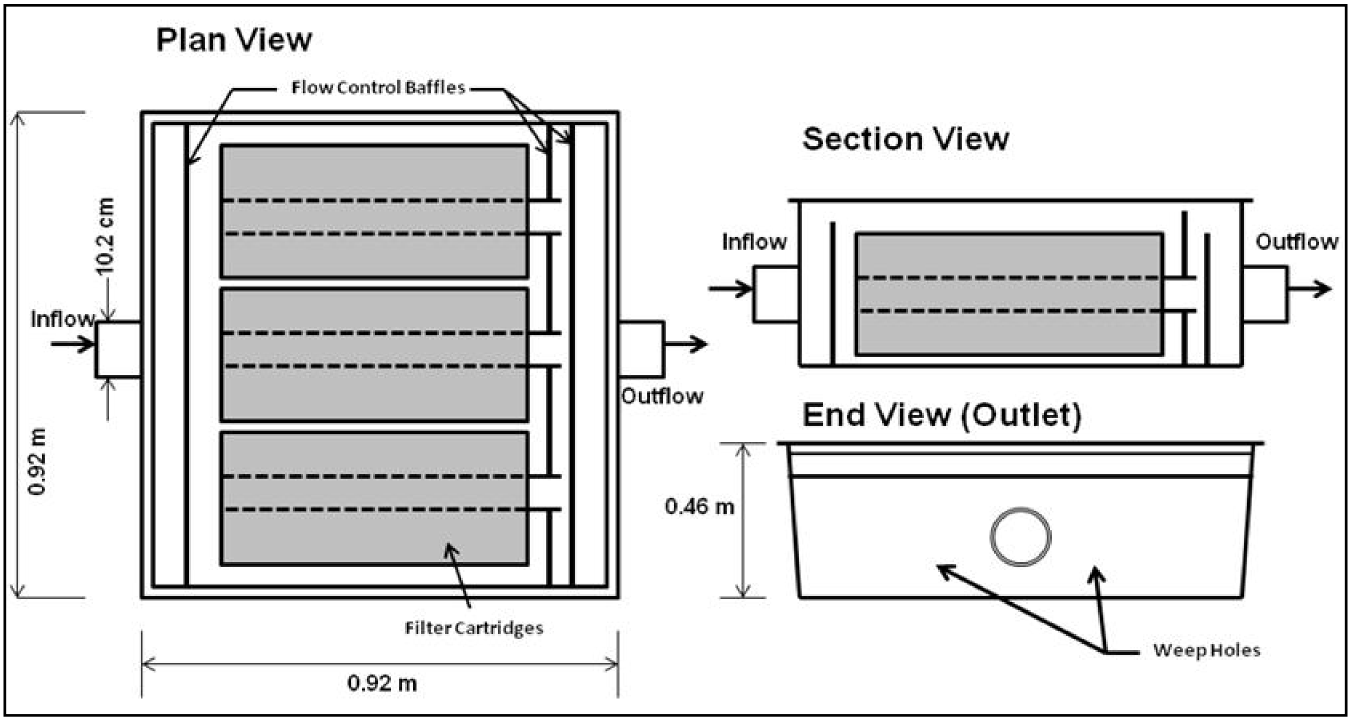

Figure 1. Test filter apparatus

structural modification including water table management (13) and/or treatment of discharge waters before and after entry into drainage tiles (3), streams, and waterways (8).

The objectives of this research are to address the subsurface water quality concerns from managed turf through the demonstration of end-of-tile filters at both the laboratory and field scale. Summaries from a laboratory, individual green, and field scale study follow.

Laboratory Evaluation and Assessment

For the laboratory study, a hydrograph generator was created to simulate tile flow discharge. Hydrographs with peak flow rates of 10, 20, and 30 gallons per minute were studied. The hydrographs were generated from a 2,000-gallon supply reservoir containing a solution of nitrate nitrogen (12 ppm), dissolved phosphorus (0.9 ppm), chlorothalonil (34 ppb), and metalaxyl (13 ppb). The initial concentrations were representative of or greater than concentrations generally measured in tile drainage discharge from managed turf.

The water was pumped through the filter assembly using the hydrograph generator. Samples were collected prior to entering the filter and after flowing through the filter. The filters contained a proprietary mixture of activated alumina, activated carbon (from coconut shells), and naturally occurring zeolite (clinoptilolite) in a cartridge design. The cartridge design was chosen because of its ease in capturing discharge from tile drains. The filters were designed by Kristar Enterprises, Inc. (Santa Rosa, CA) in a particularly low profile and footprint to minimize the required excavation for placement in-line with the drain tile as well as to maximize filter surface area with low available operating head (Figure 1).

The filter system (US Patent 7,374,364) consisted of three replaceable cartridges, each approximately 600 mm long x 200 mm diameter filled with 0.015 m^3 of granular media, in a fiberglass test structure nominally 0.92 m x 0.92 m x 0.46 m (3 ft x 3 ft x 1.5 ft). A media blend of 33.2% granular activated carbon (GAC), 34.0% zeolite (clinoptilolite), and 32.8% activated alumina (AA) by weight was used for purposes of this test. These proportions were consistent with the patent application and were selected based on limited bench scale screening tests (conducted by

Peak Flow (L/s)	NO_3-N	DRP	Chlorothalonil	Metalaxyl
0.63 (n=3)	5.2 (0.43) a*	53.5 (1.75) a	59.3 (1.89) a	31.0 (1.31) a
1.26 (n=3)	4.9 (0.56) a	53.9 (4.71) a	64.4 (7.45) a	30.1 (5.52) a
1.89 (n=3)	3.9 (0.11) b	47.3 (10.87) a	50.8 (12.05) a	25.5 (4.05) a
mean across all flows	4.7 (0.68)	51.6 (7.17)	58.2 (9.91)	28.8 (4.58)

* Mean (standard deviation) values within columns followed by different letters indicates statistically significant differences ($p < 0.05$).

Table 1. Mean (standard deviation) percent reductions in total load of nitrate-nitrogen, dissolved reactive phosphorus (DRP), chlorothalonil, and metalaxyl resulting from discharge water passing through the filter, summarized by hydrograph peak flow rate and pollutant (n represents number of replicates).

Kristar Enterprises, Inc.), but not necessarily optimized, for the intended application.

Significant reductions in concentrations and loading across all three hydrographs were measured for dissolved phosphorus (51.6%), chlorothalonil (58.2%), and metalaxyl (28.8%). Nitrate nitrogen was reduced by 4.7%. Peak flow rate had a measurable effect on the amount of pollutant removed from solution (Table 1). In general, filter removal efficiency for all four contaminants tended to decrease as peak flow rate increased across all peak flow hydrographs.

Removal efficiency also depended on the pollutant type. For example, approximately 50% percent reduction in the total loads of dissolved phosphorus and chlorothalonil was observed as a function of flow rates across all peak flow hydrographs (Table 1). Similarly, metalaxyl removal was nearly 30% of its total load. In contrast, filter removal efficiencies for N-NO_3 were significantly less (only 4-5%).

The reduction of dissolved phosphorus resulting from adherence to the activated alumina measured here is comparable to results achieved by incorporating aluminum oxide materials into the soil. However, the extent of dissolved phosphorus removal observed in this study was not as great as that observed in previously cited batch and column type studies. The reduced efficiency was attributed to shorter contact times with the filter media, a direct consequence of greater flow rates.

With respect to nitrate removal, the results were somewhat surprising. We expected greater removal efficiency than was observed. Admittedly, clinoptilolite has been identified as an ideal agent for sorbing nitrogen as ammonium and not nitrate. However, activated carbon has been shown to be an effective nitrate sorbent. Nitrate removal may be most efficiently and economically achieved through microbial denitrification prior to or after water discharge through an end-of-tile filter. Cellulosic by-product materials such as wood mulch, sawdust, and leaf compost are well-suited, abundant, and sources of carbon necessary for microbial denitrification.

Regarding chlorothalonil and metalaxyl, we assume adsorption to activated carbon was the primary removal mechanism due to their chemical structure and hydrophobic nature. Variation in chemical structure may account for the differential removal efficiencies observed for each of these pollutants. For example, chlorothalonil is significantly less water soluble (0.6 ppm) than metalaxyl (7,100 ppm). Thus chlorothalonil may be more attracted to the activated carbon in the filter cartridge than metalaxyl. As with dissolved phosphorus, total removal of metalaxyl and chlorothalonil remained relatively constant over the three studied hydrograph shapes. We attribute this trend to the high surface area of activated carbon. Again, using different types of activated carbons could increase their removal efficiency.

The removal efficiency for all contami-


Site setup at the field site in Waco, TX.

nants was consistently highest at the extremes of the rising and receding limbs of the hydrograph when the flow rates were least (and residence time high). Thus, not surprisingly, this filter design may be most effective under baseflow conditions rather than storm flow events. Additionally, the large volume of storm flow may rapidly expend the filter.

Overall, further field-scale, long-term, studies of these filters are required to determine the longevity of the filter materials. Once adsorption sites are exhausted, the filter will require replacement. Also, investigation of additional byproducts, filter designs, and blending ratios is recommended to optimize filtering capability and longevity, especially at high flows. Further development of this type of system for application in large-scale recreation watersheds where greater flows are expected is also recommended.

Green Evaluation and Assessment

Based on the findings of the laboratory study, an investigation of additional materials and byproducts was conducted. The materials and byproducts selected for this study included blast furnace slag, cement kiln dust, coconut-shell activated carbon,and two natural materials, zeolite (as clinoptilolite) and silica sand. An evaluation of the materials to remove dissolved P and three pesticides (chlorothalonil, propiconazole, and mefenoxam) from a tile-drained practice green under high-flow, storm-simulated conditions was conducted at Ridgewood Country Club.

Ridgewood Country Club is a private, regulation length, 18-hole golf course located in Waco, Texas. In operation since 1946, the course spans a total of 68.8 hectares (170 acres). Runoff and drainage from the course ultimately enters nearby Lake Waco, which is a well known, nutrient-polluted surface water body (1). The course is home to a 0.074 hectares (8,000 ft^2) experimental chipping green. Below the surface, the green is split into discrete drainage areas, each of which has its own separate drainage network to allow for different experiments. For this study, only the north half of the green was considered.

The main drain tile from the north green is routed into a 3.05 m x 3.05 m x 2.44 m covered underground structure located about 20 m south of the southern-most tip of the green. Within this

The filter system consisted of three replaceable cartridges, each approximately 600 mm long x 200 mm diameter filled with 0.015 m^3 of granular media, in a fiberglass test structure .

structure, the north drain tile is directly plumbed into a filter box previously described in the laboratory study. The filter media used in each cartridge was a 14 L blend made up of 3.5 L blast furnace slag, 3.5 L clinoptilolite, 3.5 L cococnut shell activated carbon, and 3.5 L of a 5% cement kiln dust: 95% sand mixture. The 14-L blend was manually mixed and weighed approximately 15 kg. Proportions of filters materials were determined on a volume basis because weighing out large quantities of the materials was not feasible in field.

Phosphorus in the form of PO_4^{3-}, chlorothalonil, mefenoxam, and propiconazole were applied in a single application to the green according to the manufacturers' specifications and allowed to sit for 30 minutes prior to storm event simulation. Water samples were collected by two Isco 6712 portable, automated samplers (Teledyne Isco, Inc., Lincoln, NE) that were programmed to separately collect 1 L of drainage water samples from the inlet (pre-filter interaction) and outlet (post-filter interaction) of the filter box at predetermined time intervals. The samples were collected into acid-washed, pre-rinsed 1 L jars at 5-, 10-, 15-, 20-, 25-, 30-, 45-, 60-, and 90-minute intervals, post-irrigation. At 2.1 hours, the green was again irrigated for 10 minutes with municipal water. Sampling resumed immediately following this second irrigation and using the same time intervals. This entire procedure (irrigation and sampling) was repeated a third time at 4.2 hours. Sampling ended after a total run time of 6 hours. A total of 27 samples were collected.

All influent contaminant loading rates varied with drainage flow rate. Phosphate exhibited the clearest trend with its loading rate increasing as a function of flow. This trend was less clear for propiconazole, chlorothalonil, and mefenoxam. Despite the variability in flow rates, a significant decrease in the chlorothalonil load was observed. The median decrease in chlorothalonil was 69%. The highest reduction of chlorothalonil was 96% and occurred at time = 45 minutes. In general, chlorothalonil removal was very high (> 80%) near peak flows. Approximately 90% of chlorothalonil was removed at flow rates in excess of 0.540 L s^{-1}.

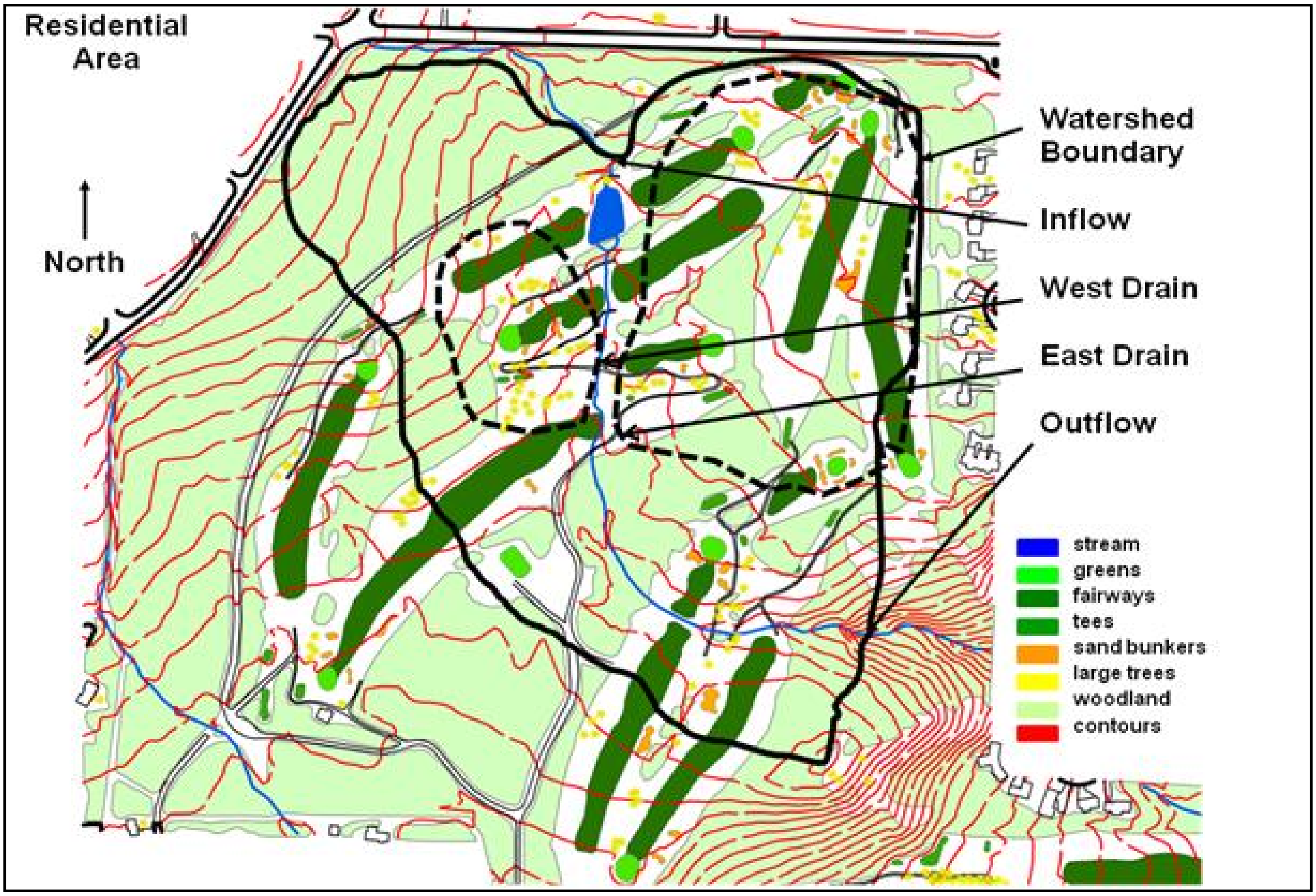

Figure 2. Northland Country Club layout with study areas.

In contrast, reductions in PO_4^{3-}, mefenoxam, and propiconazole were not statistically different. Only a 0.2% reduction in the incoming PO_4^{3-} load was measured. Korkusuz et al. (6) averaged 44% PO_4^{3-}- removal from wastewater, flowing at 2.1 L s^{-1}, by using over 11 Mg of slag. On an even larger scale, Schilton et al. (11) used nearly 19 Gg slag over a 5-year period to capture 77% P from wastewaters averaging flows of 1,389 L s^{-1} (retention time on the slag filters was approximately 3 days). So, if more slag had been was used in the present study, PO_4^{3-}- removal efficiencies may have been greater. This could be achieved by adjusting the filter design to accommodate more material, or changing the design completely. It may be that a larger filtering structure is needed to slow down the drainage inflow so that PO_4^{3-} can be removed, at least under storm conditions.

The flow rates may have also limited the removal of propiconazole and mefenoxam. Chlorothalonil is more hydrophobic than both mefenoxam and propiconazole and may be sorbed (presumably by coconut-shell activated carbon) to a greater extent, even in instances of preferential flow through the filter media. Again, changing the filter design and filter blend may improve propiconazole and mefenoxam removal.

Flow rate or retention time is the most critical factor in filter design. As shown in this study, removal of chemicals with greater solubility (propiconazole, mefenoxam, and PO_4^{3-}) was more difficult and attributed to small retention times. Conversely, removal of chlorothalonil, a less soluble chemical was achieved with significance. Designing filters with increased retention time can be accomplished by increasing the volume of filtering material, lengthening the cartridges, or reducing the flow rate by regulating the

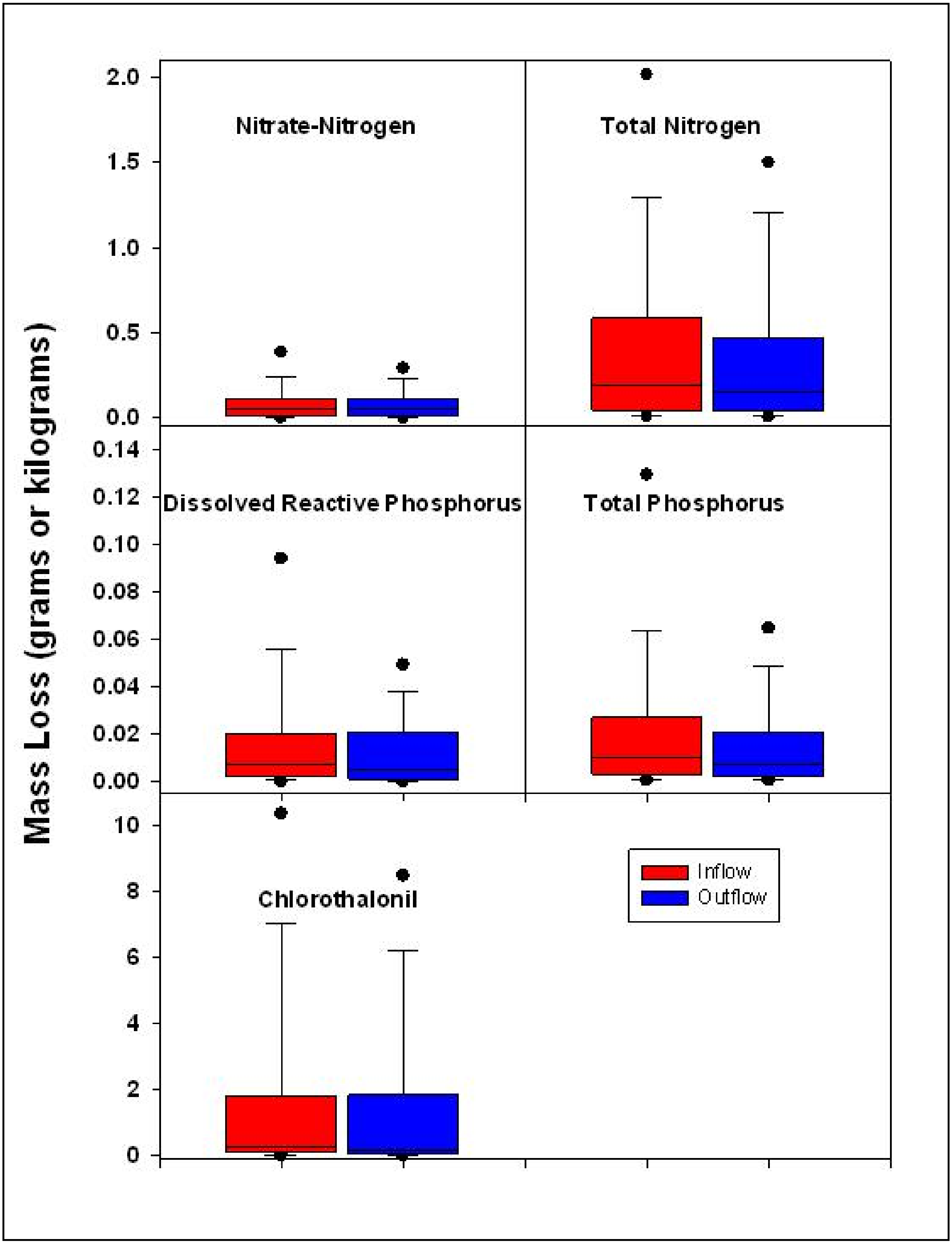

Figure 3. Inflow and outflow loading data from east drain at Northland Country Club. Nutrient loads are in kilograms, chlorothalonil data is in grams.

flow. In order to extend this application to larger drainage areas, filters must be designed with retention time in mind.

Field-Scale Evaluation

In 2009, the filter design and materials evaluated in the laboratory experiment were transferred to a drainage network at Northland Country Club (NCC) in Duluth, MN. The drainage network consists of multiple surface inlets and subsurface tile that remove water from different managed areas of the course. The NCC study area is a 21.8 ha (54 acre) sub-area of the golf course that contains 7 greens (0.3 ha), 8 tees (0.5 ha), 10.5 fairways (3.95 ha), grass roughs (8.1 ha), and 8.95 ha of unmanaged mixed northern hardwoods (Figure 2). A small stream enters the study area at the inlet and empties into a small natural detention pond once used for irrigation. After the water leaves the pond, it meanders approximately 700 meters through the study area until it exits at the outflow collection site and eventually into Lake Superior. Northland Country Club is located in a temperate-continental climatic region and is characterized by warm, moist summers requiring drainage for playability. Northland Country Club is managed at a moderate to intense level. The particular study area for this demonstration is the east drain.

The drainage water is a combination of subsurface drainage and surface flows that are collected in micro-depressions and routed to the tile. Data are collected simultaneously using Isco 6712 automated samplers at the inflow and outflow of the filter every 4,000 gallons of water that pass through the filter. This is a "real world" application of the filter and is representative of both baseflow and stormflow concentrations.

Preliminary results (2009-2011) indicate that on an event basis (67 discharge events), flow through the filter mixture reduces the loading that is discharged through the end of the tile (Figure 3). The percent reductions in median loads were - 6% NO_3, 17% total nitrogen, 29% dissolved reactive phosphorus, 30% total phosphorus, and 31% chlorothalonil. However these reductions were not statistically different. For all five pollutants measured, the peak loadings were also substantially reduced.

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