A TECHNICAL SUMMARY OF PERFORMANCE: APPLYING VIROPHOS MEDIA IN A NOVEL WET POND LITTORAL SHELF FILTER RETROFIT

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Project Overview

Wet ponds are one of the most commonly found stormwater control measures (SCMs) throughout the southeastern United States. North Carolina, in particular, has over 20,000 wet ponds used for stormwater management. While wet ponds have been shown to successfully mitigate flooding, their ability to treat stormwater runoff for pollutants has been highly varied. Consequently, recent efforts have focused on retrofitting existing wet ponds to improve their water quality performance.

Since the mid-2000's, wet ponds in North Carolina have been designed and constructed with littoral or aquatic shelves along their perimeters. Previous research in Minnesota has explored the possibility of installing media based filters along these shelves as a retrofit. Based upon this initial research, North Carolina State University's Stormwater Engineering Group retrofitted an existing wet pond (Sapphire wet pond; Fig. 1) in Rocky Mount, NC to include a littoral shelf filter equipped with ViroPhos filter media to assess the ability of the filter to provide polishing of pond effluent for nutrients.

Figure 1. Sapphire wet pond in Rocky Mount, NC.

The 3,600-ft^2 wet pond receiving runoff from a 7.3-acre residential area watershed was retrofit with a 408-ft^2 littoral shelf filter in October 2017. The filter was installed along the south bank of the wet pond (Fig. 2). The filter was installed at permanent pool elevation with an approximately 4-inch high berm separating the filter surface from the permanent pool surface. The filter was lined with an impermeable liner to prevent seepage of water from the banks of the pond and ensure only stormwater above the permanent pool would be routed through the system. Above the impermeable liner, the filter was backfilled with a 6-inch layer of double-washed #57 stone, a 3-inch layer of double-washed #87 stone, and 1.5 feet of ViroPhos filter media. The filter was drained through two 4-inch perforated underdrains that were daylighted to a swale outside of the wet pond and fitted to a 1-inch nozzle.

Figure 2. Littoral shelf filter following construction (left) and underdrain (right).

Following retrofit, Onset HOBO U20 water level loggers were installed to monitor water levels within the shelf filter and Teledyne ISCO monitoring equipment was installed to monitor hydrology and water quality associated with the retrofit. Sharp crested v-notch weirs were installed within the catch basin inlet to the pond, outlet structure of the wet pond, and within a weir box surrounding the daylighted underdrain. ISCO bubbler modules measured water levels over each weir and flow rates were calculated using stage-discharge relationships. Flow-weighted volumetric water quality samples were collected at each monitoring location (pond influent, pond effluent, and filter effluent) using ISCO programmable automated samplers and were delivered for laboratory analysis within 24 hours of rainfall cessation.

Water quality samples were analyzed at the NC State University Center for Applied Aquatic Ecology, a North Carolina Department of Environmental Quality certified laboratory. Samples were analyzed for total Kjeldahl nitrogen (TKN), total ammoniacal nitrogen (TAN), nitrate-nitrogen, total phosphorus (TP), orthophosphate (OP), and total suspended solids (TSS). Total nitrogen (TN) was calculated as the sum of TAN and nitrate, organic nitrogen (ON) was calculated as the difference of TKN and TAN, and particulate bound phosphorus (PBP) was calculated as the difference in TP and OP. Pond outlet samples represented treatment provided solely by the pond while filter samples were treated by the pond and the littoral shelf filter. Nutrient concentrations at each sampling location were statically compared using R Statistical Software. Differences were significant at $\alpha = 0.05$.

Results

Runoff successfully infiltrated the filter for the majority of the monitoring period (Fig. 3). A concern with the installation of littoral shelf filters is the biologically active nature of wet pond ecosystems and its effect on filter blinding and maintenance. Biological blinding was observed on occasion during the growing season; however, infiltration was restored following raking of the filter surface (Fig. 4).

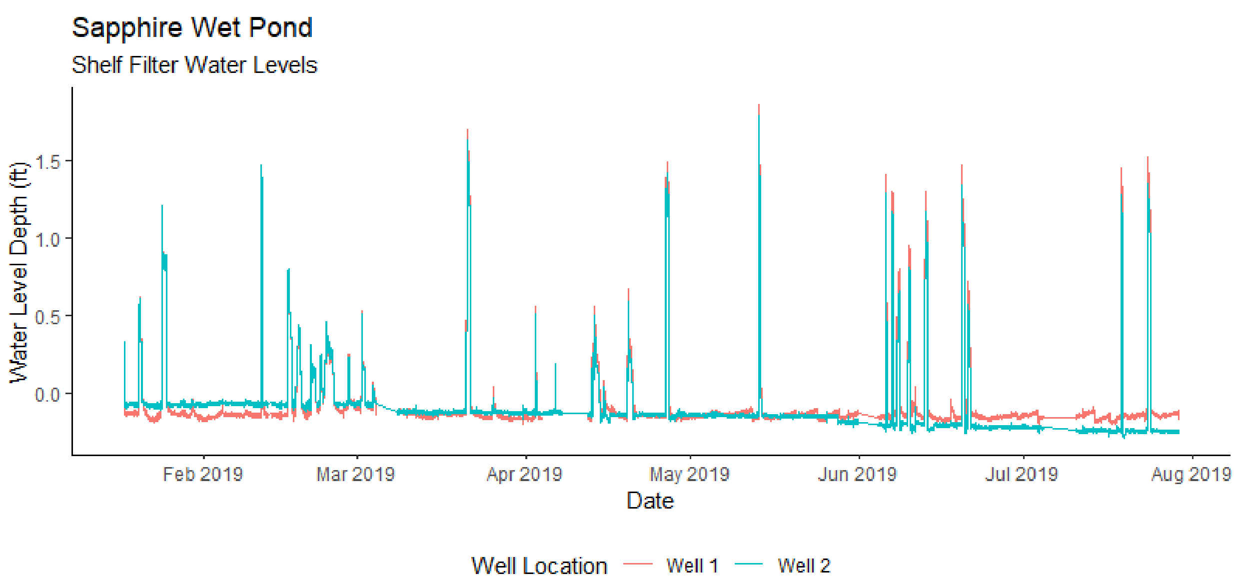

Figure 3. Water levels within the filter from June - December 2018.

Figure 4. Biological blinding of the shelf filter observed at the Sapphire pond (left) remedied by raking of the filter surface (right).

From October 2018 – June 2019, 57 storm events with rainfall exceeding 0.10 inches were observed with 20 storm events being sampled for water quality. Rainfall ranged from 0.10 to 2.16 inches with a median of 0.54 inches. Of these 20 sampled events, 18 included paired pond influent, pond effluent, and filter effluent.

An efficiency ratio (ER) was calculated to determine removal rates for the pond and filter. For the pond, ER was calculated as,

$$ER_{pond} = \frac{EMC_{Pond\ In} - EMC_{Pond\ Out}}{EMC_{Pond\ In}} \times 100 \quad (1)$$

where EMC is the event mean concentration of a pollutant.

To compare the degree of polishing provided by the filter to treatment provided solely by the wet pond, an ER was calculated to compare pond effluent to filter effluent using Equation 2.

$$ER_{filter} = \frac{EMC_{Pond\ Out} - EMC_{Filter\ Out}}{EMC_{Pond\ Out}} \times 100 \quad (2)$$

Nitrogen

Influent TN concentrations ranged from 0.86 to 2.92 mg/L, pond effluent TN concentrations ranged from 0.58 to 1.99 mg/L, and filter effluent TN concentrations ranged from 0.28 to 2.18 mg/L. Median TN concentrations for pond influent, pond effluent, and filter effluent were 1.67, 0.93, and 0.77 mg/L, respectively. When compared to pond effluent, filter effluent TN concentrations were reduced for 78% of events. The pond was able to significantly reduce TN concentrations ($p<0.001$) with a median ER_{pond} of 38% while the filter provided an additional significant reduction ($p=0.04$) with a median ER_{filter} of 11%.

Of its individual species, the filter performed best at reducing TAN, likely due to the transformation of TAN to nitrate as the filter significantly increased nitrate concentrations ($p<0.001$) by a median of 92% (Fig. 5). This significant increase in nitrate is attributed to the aerobic environment within the filter supporting the aforementioned transformation of TAN to nitrate. However, filtration of particulate-bound ON and some possible sorption of N produced significant removal of TN.

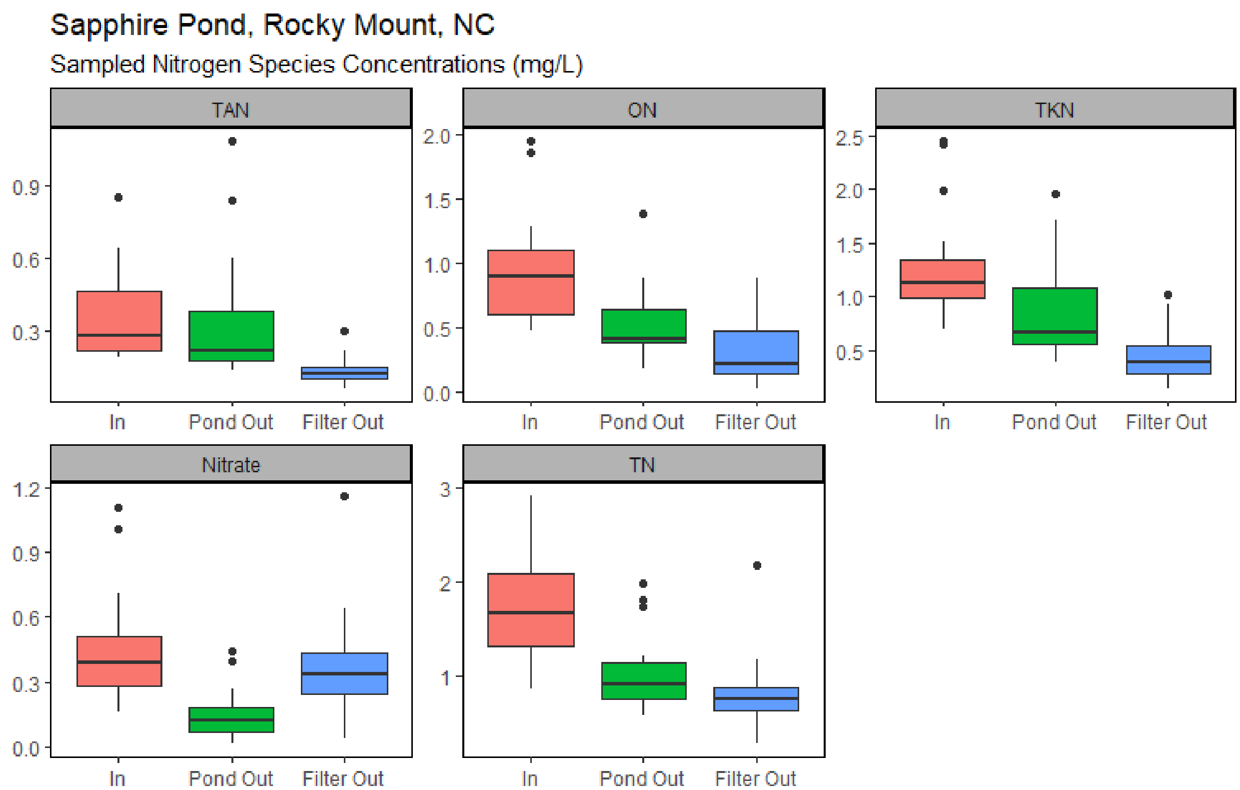

Figure 5. Nitrogen species concentrations (mg/L) at each monitoring location at Sapphire wet pond in Rocky Mount, NC.

Phosphorus

TP concentrations ranged from 0.07 to 0.47 mg/L for pond influent, 0.02 to 0.33 mg/L for pond effluent, and 0.01 to 0.15 mg/L for filter effluent with median TP concentrations of 0.17, 0.12, and 0.06 mg/L for each, respectively. TP concentrations were significantly reduced by the wet pond ($p<0.006$) and the ViroPhos filter provided further significant reductions ($p=0.002$). The median TP ER_{pond} was 32% while median ER_{filter} was 62%.

Naturally, as a filter, the best P species removal by the filter was associated with PBP (median ER = 82%; Fig. 6). However, the additional significant removal of OP ($p<0.001$) is promising. As OP is the dissolved fraction of TP, wet ponds typically struggle to treat runoff for OP. While the pond itself reduced OP by a median of 48%, this reduction in OP concentration was not significant. The chemical properties of the ViroPhos filter likely provided the sorption capacity and rates necessary to account for the significant reductions observed from the filter.

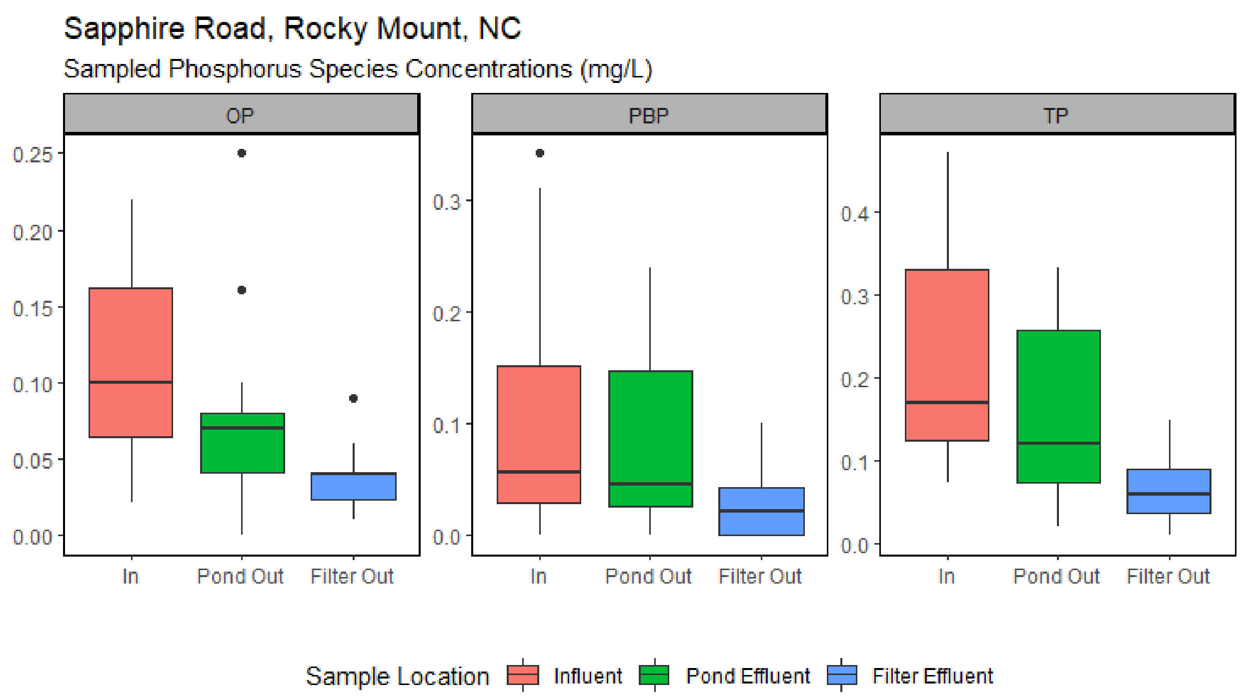

Figure 6. Phosphorus species concentrations (mg/L) at each monitoring location at Sapphire wet pond in Rocky Mount, NC.

Conclusions

As improving pond performance with respect nutrient removal is imperative, significant reductions in TN and TP provided by polishing pond effluent through the retrofit ViroPhos littoral shelf filter are very promising. When compared to median concentrations of TN and TP in runoff received by the wet pond, the littoral shelf filter provided reductions of 54% and 65%, respectively.

An important caveat in this study is the degree of treatment received with respect to total runoff volume entering the pond. While the filter did significantly reduce TN and TP concentrations, the overall degree of treatment may only be minimal when compared with the total volume of runoff that did not infiltrate through the filter media. At the Sapphire wet pond, the median percent of volume that was polished by the filter was 10% of total volume discharged from the pond.

While oversizing future installations of retrofit littoral shelf filters may allow greater treatment capacity, it may prove to (1) be cost prohibitive, (2) negatively affect the hydraulics of the pond with respect to flood mitigation, or (3) both. Lastly, maintenance requirements should be carefully considered as biological activity may result in blinding of littoral shelf filters. As such, maintenance requirements may be extensive dependent upon vegetative characteristics of individual sites.