NC STATE UNIVERSITY

NC Policy Collaboratory

Falls Lake Nutrient Management Study: 2019 – 2020 Annual Report

Green-Street Retrofit Study

Wet Pond Retrofit Design Guidance

Investigators:

William F. Hunt, III, PhD, PE[1]

Jeffrey P. Johnson, PhD, EI[2]

Sarah Waickowski, PE[2]

October 15, 2020

[1] William Neal Reynolds Distinguished University Professor and Extension Specialist, Department of Biological and Agricultural Engineering, NC State University

[2] Extension Associate, Department of Biological and Agricultural Engineering, NC State University

Background

Green streets are quickly becoming a popular catchment-scale retrofit for municipalities wishing to achieve multiple environmental, social, and economic goals. “Green streets” are defined by Shaneyfelt et al. (2017) as “transportation corridors in which low impact development is employed as a design principle by using a variety of green stormwater infrastructure (GSI) practices to treat direct transportation surface drainage in the right-of-way.” Green streets retrofits have been shown to significantly reduce stormwater runoff volumes and nutrient loads, improve urban air quality, mitigate heat island effects, and increase property values (Page et al., 2015; Shaneyfelt et al., 2017). This research examined a particularly popular type of green street retrofit, suspended pavement street systems. Suspended pavement systems utilize either un-compacted native soil, or engineered soil media underneath sidewalks to treat stormwater runoff. These systems typically include one or more full-canopy trees to provide additional evapotranspiration and nutrient uptake while meeting urban tree requirements. This research examined the nutrient removal capabilities of a popular suspended pavement street system to determine the potential impact of scaling green street retrofits on water quality in Falls Lake.

Because ponds treat relatively large watersheds, any means of improving their performance has the potential for widespread effect. This project will build off the previous literature review on floating wetland islands (FWIs). Using the available data and recommendations from the literature provided in the Jordan Lake study, design guidance was developed to aid regulators, practitioners, and the development community in implementation of FWI and other available wet pond retrofits. This guidance will be key for future projects needed to meet regulatory requirements for existing developments in the Falls Lake watershed to reduce nutrient loads.

Greet-Street Retrofit Study

Municipalities within the Falls Lake Watershed have increasing populations and new development, which lead to greater water quality impacts on Falls Lake. Stormwater control measures (SCMs) such as DeepRoot Silva Cells® are implemented to mitigate these impacts. Silva Cells® are a suspended pavement system approved by the North Carolina Department of Environmental Quality (NCDEQ) to manage stormwater runoff. This SCM promotes urban tree growth and provides structural support while treating urban runoff. NCDEQ (2018a) credits SCMs based the loading ratio (water quality runoff volume to SCM storage volume) and in-situ hydrologic soil group (HSG). Previous research in North Carolina has shown 100% sized Silva Cells® installed over HSG A soils significantly reduce pollutants and mitigate peak flows (Page et al. 2015). North Carolina State University (NCSU) and the City of Durham monitored two undersized Silva Cell® systems (North and South) with in-situ HSG D soils for water quality and hydrologic improvement from May 2019 to June 2020. The North system had a loading ratio of 8.6:1, and the South system had a loading ratio of 1.9:1 (Figure 1, Table 1). Data were collected using automated stormwater samplers, pressure transducers, and rain gauges (tipping bucket and manual). The data were analyzed for total suspended solids (TSS), nitrate-nitrite (NO_x), total kjeldahl nitrogen (TKN), total ammonical nitrogen (NH_3), ortho-phosphate ($O\text{-}PO_4^{3-}$), and total phosphorus (TP). Total nitrogen (TN) event mean concentrations (EMCs) were calculated using respective TKN and NO_x samples.

Table 1. North and South Silva Cell® system characteristics.

Characteristic	North system	South system
Drainage area (ac)	0.30	0.15
Curve number (CN)	98	98
Percent impervious (%)	79	87
Number of 2X DeepRoot Silva Cell® units	16	36
Water quality volume: storage volume	8.6:1	1.9:1

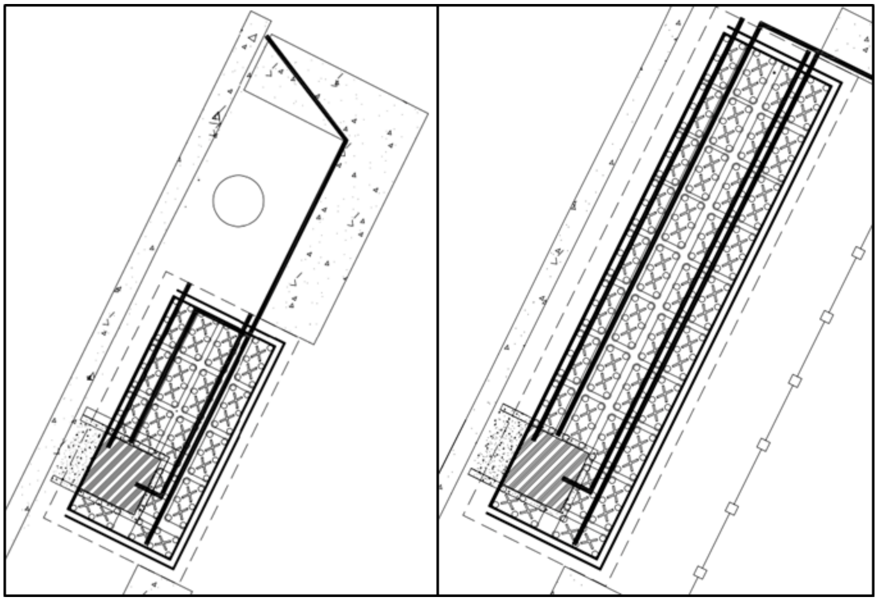

Figure 1. Plan view of Durham Silva Cell® systems.

Nonparametric methods from Helsel and Hirsch (2002) were used to statistically analyze paired influent and effluent water quality data. The data were tested for symmetry using the m-out-of-n bootstrap symmetry test (Miao et al. 2006). For symmetrical data, the Wilcoxon signed-rank test was used to detect statistical significance between influent and effluent EMCs. Non-symmetrical data were analyzed for significance using the paired samples sign test. All statistical analyzes were calculated using R 3.6.2 software (R Core Team 2019), and statistical significance was established at $\alpha = 0.05$. The limited number of South samples caused a reduction in statistical power and the ability to detect the system's water quality improvement.

NCSU collected 16 and 5 effluent water quality samples from the North and South systems, respectively. The South Silva Cells® generated outflow when the rainfall depth was at least 1.00 inch. Median North TN and TP EMCs were 1.18 and 0.20 mg/L, respectively (Table 2); bypass or overflow occurred during 12 of the 61 hydrologic events. Median South TN and TP EMCs were 0.79 and 0.09 mg/L, respectively. The South Silva Cells® generated bypass during 11 of the 61 storm events. There were significant differences between influent and effluent North TKN, TN, TP, and TSS EMCs. Reductions in pollutants are attributed to filtration, sedimentation, and the system's internal water storage (IWS). Previous research has shown IWS promotes denitrification (Brown and Hunt 2011; Passeport et al. 2009). These results also suggest Silva Cells® can provide water quality treatment regardless of the in-situ HSG.

Table 2. Median pollutant EMCs.

Sampling location	Number of samples	TKN (mg/L)	NO_x (mg/L)	TN (mg/L)	NH_3 (mg/L)	TP (mg/L)	$O\text{-}PO_4^{3-}$ (mg/L)	TSS (mg/L)
Inlet	16	1.16	0.23	1.47	0.07	0.30	0.07	83
North	16	0.91	0.19	1.18	0.21	0.20	0.13	9
South	5	0.47	0.31	0.79	0.05	0.09	0.02	13

The project site's target TN and TP loading rates (Table 2) were calculated using the NCDEQ (2018b) Stormwater Nitrogen and Phosphorus (SNAP) Tool. Annual TN and TP loading rates from each Silva Cell® system were calculated using effluent and bypass volumes and respective EMCs. Annual TN and TP loading rates from the North Silva Cells® were 2.03 and 0.40 lb/ac/yr, respectively. Annual TN and TP loading rates from the South system were 1.16 and 0.13 lb/ac/yr, respectively. These loading rates are well below the site's target rates site and indicate undersized Silva Cells® have the potential to mitigate the environmental impacts associated with development.

Table 3. Target and annual TN and TP loading rates.

Pollutant	Target loading rate (lb/ac/yr)	North loading rate (lb/ac/yr)	South loading rate (lb/ac/yr)
TN	13.33	2.03	1.16
TP	2.80	0.40	0.13

References:

Brown, R.A., & Hunt, W.F. (2011). Underdrain configuration to enhance bioretention exfiltration to reduce pollutant loads. *Journal of Environmental Engineering, 137*(11), 1082-1091.

Helsel, D.R., & Hirsch, R.M. (2002). Statistical methods in water resources. In *Hydrologic Analysis and Interpretation*. U.S. Geological Survey.

Miao, W., Gel, Y.R., & Gastwirth, J.L. (2006). *A new test of symmetry about an unknown median*. In *Random walk, sequential analysis and related topics- A festschrift in honor of Yuan-Shih Chow.* World Scientific Publisher.

NCDEQ. (2018a). *Stormwater control measure credit document*. North Carolina Department of Environmental Quality. https://deq.nc.gov/sw-bmp-manual

NCDEQ. (2018b). *Nutrient practices and crediting.* North Carolina Department of Environmental Quality. https://deq.nc.gov/about/divisions/water-resources/planning/nonpoint-source-management/nutrient-offset-information

Page, J.L., Winston, R.J., & Hunt, W.F. (2015). Soils beneath suspended pavements: An opportunity for stormwater control and treatment. *Ecological Engineering, 82*, 40-48.

Passeport, E., Hunt, W.F., Line, D.E., Smith, R.A., & Brown, R.A. (2009). Field study of the ability of two grassed bioretention cells to reduce stormwater runoff pollution. *Journal of Irrigation and Drainage Engineering, 135*(4), 505-510.

R Core Team. (2019). *R: a language and environment for statistical computing* (Version 3.6.2). R Foundation for Statistical Computing. https://www.R-project.org/

Shaneyfelt, K.M., Anderson, A.R., Kumar, P., Hunt, W.F., 2017. Air quality considerations for stormwater green street design. *Environmental Pollution*, 231, 768–778. https://doi.org/10.1016/j.envpol.2017.08.081

Wet Pond Retrofit Design Guidance

Pollution from stormwater runoff continues to be a primary water quality concern, linked to the degradation of streams and lakes in developing areas. Wet ponds are one of the most commonly found practices used to manage stormwater runoff throughout the southeastern United States. North Carolina, in particular, has over 20,000 wet ponds used for stormwater management. While wet ponds have long been used to successfully mitigate flooding and remove total suspended solids (TSS) by capturing and temporarily storing runoff from storms, the ability of ponds to treat stormwater runoff for nutrients and pathogens has been highly varied because of a lack of existing mechanisms to remove pathogens and the dissolved fraction of nutrients. To address these issues and improve nutrient and pathogen removal in ponds, recent efforts have focused on retrofitting existing wet ponds to improve their water quality performance.

Figure 2. Typical stormwater wet pond with forebay, main body, and outlet control structure.

This report will provide guidance on two retrofit opportunities for wet ponds in North Carolina: (1) floating treatment wetlands and (2) littoral shelf filters.

Floating Treatment Wetlands

Floating treatment wetlands (FTWs), also known as floating wetlands, floating islands, and floating treatment islands, are a hydroponic system that employs vegetated floating mats or trays to provide pollutant removal in surface water settings (Figure 3). As vegetation grows on the FTWs, plant roots are suspended within the water column beneath and use nutrients in the water for growth. Sticky biofilms that grow on plant roots and the bottom surface of the FTWs also uptake nutrients and trap particulate bound pollutants (Figure 3). In addition to the removal of pollutants from the water column, FTWs also provide benefits including improved habitat, diversity, and aesthetics.

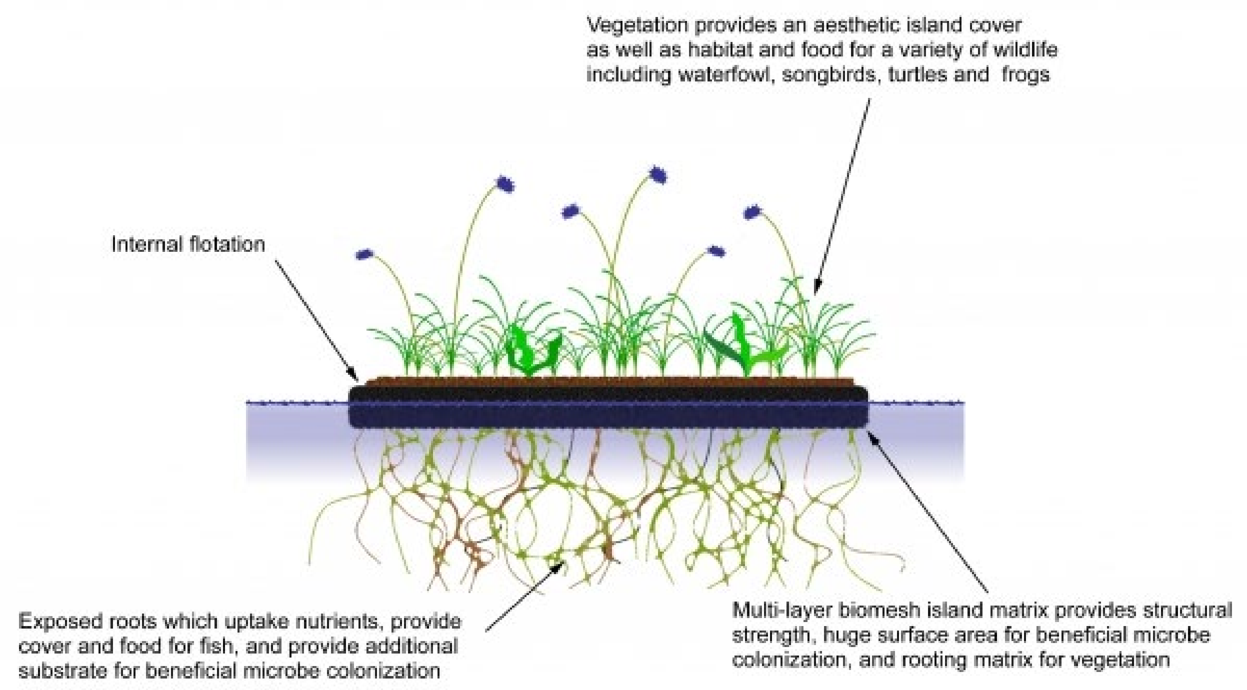

Figure 3. Floating treatment wetlands are a hydroponic system with multiple pollutant removal mechanisms and benefits.

At the surface, FTWs can be buoyed using a proprietary material similar to commercial-grade plastic or Styrofoam, or they can be constructed from connected sealed barrels, plastic pipe, or other floatation devices (Figure 4). The surface of each FTW is planted with native wetland vegetation, including grasses and flowering plants to provide aesthetic and water quality benefits.

Figure 4. Floating treatment wetlands in a wet pond forebay in New Zealand (left) and in a wet pond in China (right).

Requirements

FTWs are a popular retrofit option because not only do they provide water quality and habitat benefits, they are relatively straightforward to design and install. One of the key advantages to FTWs is that they do not impair an existing wet pond's ability to mitigate peak flows and they do not require heavy equipment for installation. However, there are two basic requirements that must be met before FTWs can be installed. First, the wet pond needs to be sufficiently deep. A minimum depth of four feet is recommended to ensure that roots from FTW vegetation to do not reach the sediment on the bottom of the pond and root the FTW in-place. When this happens, FTWs are not able to move with the temporary pool during rain events and will capsize. The second requirement is that the pond must be free of invasive weeds that can attach and overwhelm the FTW. Not only will the invasive weeds become unsightly, they will also hold FTWs in-place causing submergence and hindering functionality.

Installation

FTWs can be purchased from many providers in the United States and can be made in different shapes and sizes. They can even be assembled to represent a business logo or other design. To receive credit for water quality benefits, the North Carolina Department of Environmental Quality requires that at least 5% of a pond's surface area be covered with FTWs. However, research suggests that a greater coverage area (e.g., 20%) may be necessary to realize significant water quality benefits.

FTWs work best when polluted water flows through their suspended root zone. Therefore, FTWs should be installed in a manner that is perpendicular to the flow of water through the pond. For example, stringing straight lines of FTW across a wet pond will force water to flow through the root zone and receive treatment. Another option is to form a ring of FTWs surrounding a pond's outlet structure, also ensuring that runoff flows through the root zone. Regardless, care should be taken to ensure that FTWs are installed away from the pond shelf to maintain a minimum depth of four feet.

Once positioned, FTWs can be anchored in place using plastic cord or chains and cinderblocks. FTW manufacturers also recommend connecting FTWs together and tethering groups to trees or stakes installed in upland areas surrounding the wet pond. Regardless of which method is used, cables should have enough slack to allow FTWs to rise from the permanent pool elevation to above the rim of the outlet structure during large rain events to prevent submergence or capsizing.

Maintenance

FTW maintenance can be broken down into three main categories: (1) vegetation protection, (2) vegetation maintenance, and (3) hardware maintenance. Initial maintenance of FTWs includes using exclusion techniques to protect recently planted vegetation from predators during the first growing season. If vegetation loss occurs, plants should be replaced promptly to ensure adequate coverage of FTWs. As FTW vegetation matures, volunteer species will become present on FTWs. Trees and shrubs should be removed from FTWs as their weight can cause FTWs to submerge or capsize. Invasive weeds should be removed as they present to prevent overwhelming existing vegetation. Lastly, FTWs should be inspected for damage and repaired as needed. This includes inspecting and replacing tethering cords and chains as needed to ensure that FTWs continue to be held in the proper position.

Littoral Shelf Filters

Since the mid-2000's, wet ponds in North Carolina, and other states, have been designed and constructed with littoral or aquatic shelves along their perimeters for safety and aesthetics. An attractive area of space for retrofit, recent research has explored the possibility of installing media based filters along these shelves as a retrofit to improve nutrient and pathogen removal in wet ponds.

Littoral shelf filters are installed at the permanent pool elevation and receive runoff as a pond fills from permanent pool to temporary pool elevation (Figure 5). Runoff that is routed through the filter receives treatment via filtration and chemical reactions with high-flow media.

Figure 5. Littoral shelf filter installed at a wet pond in Rocky Mount, NC.

Requirements

While littoral shelf filters can provide water quality benefits, they do effect a wet pond's retention volume and as such permits and engineering will likely be required. Not all ponds will be a good fit for littoral shelf filters as space is needed to install the filter alongside the pond and an existing pond's geometry might complicate design and installation. Similar to FTWs, ponds must be free of invasive weeds, moss, and excessive algae growth as this will clog the filter. If invasive weeds and algae are present, an aquatic vegetation expert should be consulted for treatment options before installing a littoral shelf filter.

Design

At first glance, littoral shelf filters resemble a sand filter (Figure 6). They should be installed at the permanent pool elevation and be separated from the water surface by a 3-4 inch berm. The amount of inflow to the pond that can be treated by the filter is roughly equal to the ratio of the filter surface area to the permanent pool surface area. Filters should consist of 1.5-2 feet of high-flow filter media (e.g., infiltration rates exceeding 2 in/hr). Beneath the filter media should be a choking stone layer and a drainage layer including a perforated underdrain system. Lastly, littoral shelf filters should be installed with a thick impermeable liner surrounding the entire interior of the system to prevent seepage from ground water or from the pond's banks.

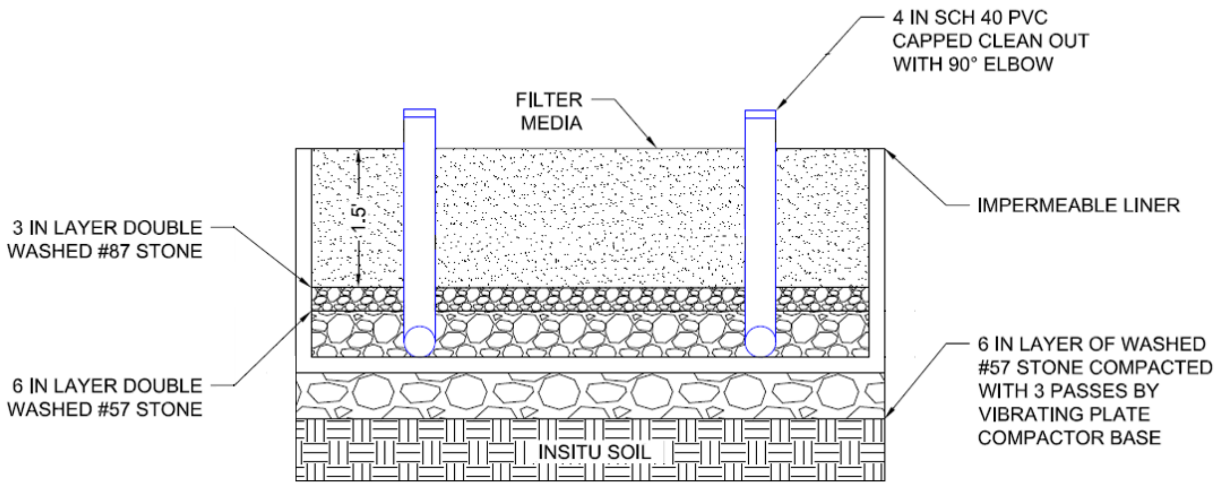

Figure 6. Example cross-section schematic of a littoral shelf filter.

Installation

Installation of littoral shelf filters will require heavy equipment for excavation and grading (Figure 7). The wet pond should be drained several days prior to installation using the emergency draw down valve installed near the outlet control structure. During installation, care should be given to protect the high-flow media from fines to prevent clogging. It is also imperative to properly install the impermeable liner. It is recommended that the impermeable liner be order to-size for the filter to prevent possible leaks resulting from sealing sections of liner together. Contractors should also ensure that stakes and pins are not used to hold the liner in-place while being backfilled and should give consideration to protecting the liner from punctures during installation of rock and media. Holes in the impermeable liner will compromise the functionality of the system. Lastly, side slopes should be protected to prevent erosion from clogging the filter surface.

Figure 7. Littoral shelf filter being constructed (left) and following construction (right) in Wilmington, NC.

Maintenance

As the filter receives runoff from the pond, sediment and other material will begin to accumulate on the surface of the filter. Accumulated sediment, trash, and biological material (e.g., algae) should be removed to prevent clogging of the filter media. Restorative maintenance of filter media infiltration can be achieved by raking the top layer of surface media after removing accumulated debris (Figure 8). Volunteer vegetation will establish on the filter surface requiring quarterly weeding to protect the filter media.

Figure 8. Biological blinding of a littoral shelf filter (left) remedied by raking of the filter surface (right).