APPENDIX B

RDU Stormwater Control Measure Implementation Strategy

RS&H

March 23, 2023 *(Revised June 2023)*

RDU Stormwater Control Measure (SCM) Implementation Strategy

RDU

RDU PE3 Subsurface Gravel Wetland Implementation Strategy

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List of Abbreviations and Acronyms

Built Upon Area .... *BUA*
Department of Energy, Mineral, and Land Resources .... *DEMLR*
Department of Natural Resources and Environmental Control .... *DNREC*
Department of the Environment .... *DOE*
Department of Transportation .... *DOT*
Department of Water Resources .... *DWR*
Environmental Site Design .... *ESD*
Event Mean Concentration .... *EMC*
Federal Aviation Administration .... *FAA*
Internal Water Storage .... *IWS*
North Carolina Department of Environmental Quality .... *NCDEQ*
North Carolina Department of Transportation .... *NCDOT*
North Carolina State University .... *NCSU*
Parking Economy 3 .... *PE3*
Raleigh-Durham Airport Authority .... *RDUAA*
Submerged Gravel Wetland .... *SGW*
Total Nitrogen .... *TN*
Total Phosphorus .... *TP*
Total Suspended Solids .... *TSS*
United States Environmental Protection Agency .... *USEPA*
University of New Hampshire .... *UNH*
Water Quality Volume .... *WQV*

1 Introduction

To accommodate existing and future demands for an economy parking product, the Raleigh-Durham Airport Authority (RDUAA) needs to expand the Parking Economy 3 facility (PE3). To mitigate the potential for adverse effects of increased stormwater runoff expected as part of the expansion, and to adhere to the requirements of the RDU Sustainability Management Plan, RDUAA is developing a project-specific stormwater management plan that includes a more advanced stormwater control measure (SCM). This SCM, which relies on Submerged Gravel Wetland (SGW) technology and is rather new to North Carolina, has been previously demonstrated in many states along the eastern seaboard and is in the process of being approved for use on projects by the North Carolina Department of Transportation (NCDOT). The SGW is expected to meet or exceed existing North Carolina SCM requirements as well as help address airport operations and site location challenges.

The following pages introduce the SGW technology, the biogeochemical processes that lead to stormwater pollutant removal, and a present conceptual design. The next section summarizes the applicability of the technology to the PE3 project, and the third section outlines how Federal Aviation Administration (FAA) and North Carolina Department of Environmental Quality (NCDEQ) stormwater regulatory requirements will be achieved with this SGW stormwater control measure.

1.1 Background on SGWs

SGWs have traditionally been used for wastewater treatment due to their ability to capture and retain high levels of pollutants. Until recently, the use of SGWs in stormwater management and regulatory guidance on the technology were limited. However, research in the early 2000s by the University of New Hampshire (UNH) Stormwater Center began to demonstrate the application of the control measure for stormwater management. Through UNH studies, a Stormwater Center Subsurface Gravel Wetlands Design Specification document was developed in 2009 (UNH Stormwater Center, 2009). Since that time, many states in the eastern U.S. have developed regulatory guidance and established design criteria with benchmarks for SGW applications. As knowledge of the SCM expands, permitted SGW projects are becoming more commonplace. Although found nationwide, some regionally applicable examples of permitted and publicized SGW projects are located in North Carolina, Maryland, Delaware, and Massachusetts (Dragonfly Pond Works, 2019) (EA Engineering, Science, and Technology, n.d.) (Delaware Business Times, 2021) (USEPA, 2016).

Further, the United States Environmental Protection Agency (USEPA) has promulgated a Stormwater Best Management Practice Stormwater Wetland fact sheet (USEPA, 2021) that describes subsurface flow wetlands, of which SGWs are a subset. This endorsement by USEPA also demonstrates this stormwater treatment technology's viability and efficacy.

The SGW system consists of one or more treatment cells or ponds, which are filled with a gravel substrate material, topped with wetland soil, and seeded with wetland plants. Through a series of perforated underdrain pipes and outfalls, stormwater runoff replicates a high groundwater table within the gravel layer. The outfall for each cell is constructed at a depth that will maintain the constant water level to create the characteristic saturated soil conditions of a wetland. Wetland vegetation is rooted in the top layers of soil and choker stone, which is artificially saturated, allowing for enhanced water quality treatment through biogeochemical processing and bioremediation of pollutants. Algae, bacteria, and other microbes also establish within the gravel substrate and provide biological nutrient sequestration. The anaerobic conditions at the bottom of the SGW can also contribute to denitrification and other treatment processes (Atlanta Regional Commission, 2016). The SGW design and inflow capacity is planned such that soil saturation conditions should not result in standing or ponded water above the soil surface except for brief periods during and immediately after rain events. To further prevent prolonged surface water inundation after a storm event, perforated riser pipes are used to drain water from the SGW surface to subsurface gravel and aggregate stone layers.

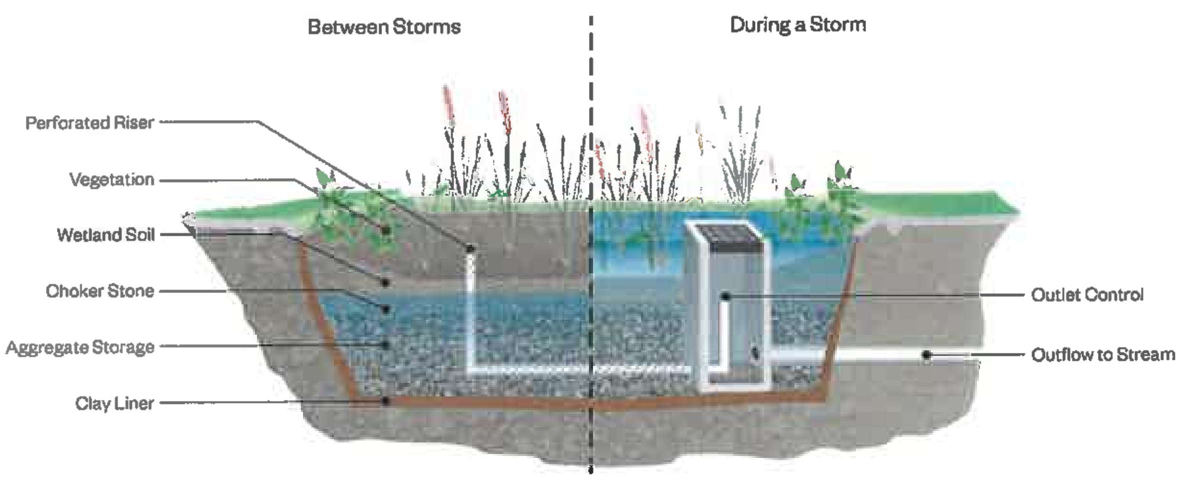

Figure 1: Rendering of a SGW from the Walnut Creek Wetland Center. Image from City of Raleigh (2022).

Figure 1 shows the design features of a typical SGW, which includes a perforated riser, a gravel substrate with differing sizes of stone, an optional impervious layer (a clay liner in this scenario), and an outflow pipe serving as the SGW's outfall to adjacent receiving waters.

Results from SGW performance research conducted for this study, in conjunction with conversations between the design team and researchers at North Carolina State University (NCSU), support the assertion that SGW technology is suitable for site conditions and space requirements. The following sections highlight the viability of this option for the RDU PE3 project, combining optimal qualities of dry and wet facilities (in alignment with FAA standards) while meeting and potentially exceeding NCDEQ's performance guidance.

1.2 Benefits of SGWs for the PE3 Project

SGWs are commonly used in retrofit scenarios when current stormwater controls are not performing adequately, water quality is not improving to the level necessary, or there are issues with stormwater quantity and flooding. They are also preferred over other SCMs due to their relatively low land consumption requirements (Atlanta Regional Commission, 2016) (Knox County Tennessee, 2008). Most often, SGWs are used for treating runoff from mostly contiguous impervious areas such as parking lots, roadways, and industrial areas, which may have large pollutant loads.

1.2.1 Airport Limitations

Rapid surface water drawdown times make SGWs an applicable and preferential method of airport stormwater control in alignment with the FAA standards (FAA, 2013) (FAA, 2020). Dry ponds also minimize periods of standing water immediately following storm events and primarily remain dry; however dry pond facilities are much less effective than other SCMs at sequestering and removing pollutants of concern, and as such are not typically allowed as primary SCMs under North Carolina regulations. However, facilities at or near airports may use dry pond facilities provided the stormwater management minimum criteria are met, but dry ponds do not achieve the same level of water quality improvement that other SCMs attain; and therefore, are not preferred for this type of project.

Wet facilities, such as wet ponds and constructed stormwater or scrubbing wetlands, typically provide greater water quality improvements compared to dry facilities and are also primary SCMs allowable by NCDEQ. However, wet ponds cannot be used at airports, or for the PE3 project in particular since their designs involve permanent or semipermanent standing water. These conditions attract birds and other species that create wildlife hazards to airport operations and present a safety concern for the flying public. The SGW, therefore, is an acceptable SCM alternative since it functions like a wetland with typical wetland plants, soils, and pollutant removal processes without the necessity for prolonged surface inundation or standing water conditions.

1.2.2 Geologic Site Constraints

The PE3 project is located in an area identified during preliminary geologic studies as having Hydrologic Soil Group C soils (Web Soil Survey, 2023). Hydrologic Soil Group C soils typically have a higher proportion of clay than A or B soils, which primarily consist of sand and loam. Because there is more clay, soils are less permeable and water transmission through the soil is restricted (USDA, 2007). SGWs are recommended for projects where there are poorly drained soils such as C or D hydrologic soils because they do not rely on infiltration (Maryland Department of the Environment, 2009). In addition, the PE3 project sits atop a layer of generally impervious partially weathered rock and bedrock. This natural liner eliminates the need for an artificial geotextile fabric or clay liner. Installed liners could fail over longer time scales due to contraction and expansion, or they could be compromised during the installation of the SGWs. By using a natural liner, which is inherently more stable, the SGWs and the overall project is more resilient.

Bioretention cells were considered as a project alternative since they also provide similarly effective pollutant treatment without prolonged periods of surficial inundation or standing water. Bioretention cells are constructed shallow stormwater basins, which remove pollutants and reduce runoff quantities through soil and substrate infiltration, filtration, and microbial bioremediation. Since these SCMs rely on rapid stormwater infiltration into underlying soil layers and substrate, slowly permeable soils and impermeable layers such as bedrock are not ideal for applications of the bioretention cell without underdrainage (Jarrett, 2022). In addition, unlike SGWs, soils and substrata in bioretention cells without internal water storage (IWS) are not inherently designed to remain saturated and therefore do not have the same pollutant removal efficacy as a constructed stormwater wetland system. Therefore, the geologic conditions at the PE3 project site support the use of SGWs.

1.2.3 Alignment with the RDUAA Sustainability Management Plan

The RDUAA released their Sustainability Management Plan in February 2023, which includes two focus areas relating to this project: Land Use and Natural Resources, and Water and Stormwater. The Airport is committed to environmental stewardship and conservation of natural resources, which include wildlife, surface water, and wetlands. The Airport has also committed to implementing best practices in stormwater management to minimize flooding and erosion while protecting water quality in the Crabtree Creek Watershed of the Neuse River Basin (Raleigh-Durham Airport Authority, 2023). By using SGWs for the management of stormwater runoff from the parking lot project, the RDUAA is demonstrating its commitment to the Sustainability Management Plan by reducing pollutant loads in stormwater runoff, implementing wetland systems with multiple ecosystem functions, and minimizing the potential for flooding and erosion of the surrounding lands. In general, the use of SGWs exceeds regulatory standards and requirements for an airport project and advances the sustainability and resiliency of the Airport as a whole.

1.3 Stormwater Management Regulatory Standards

Stormwater management regulations and standards for this project are defined by the FAA and the NCDEQ. This project follows the FAA guidance regarding stormwater drainage design and reducing wildlife hazards (FAA, 2013) (FAA, 2020). To prevent wildlife attraction to stormwater wetland systems, the SGWs will not have ponded water beyond 48 hours following a rainfall events.

While SGWs are not yet an approved SCM by the NCDEQ, under 15A North Carolina Administrative Code 02H.1003(6), the permitting authority, in this case the Department of Energy, Mineral, and Land Resources (DEMLR), can approve projects that do not comply with all the provisions of the [stormwater rules] on a case by case basis if the applicant can demonstrate that the project provides equal or better stormwater control and equal or better protection of waters of the State than the requirements of this Section (NCDEQ, 2017). Based on case studies and regulatory guidance from other states, it is clear that SGWs provide equal and in most cases, better stormwater control and treatment levels than other already approved SCMs. Preliminary assessments of the pollutant reduction capacity of SGWs for the RDU PE3 project are discussed in the following section.

The proposed SGW design at RDU will fulfill the NCDEQ's requirement that SCMs be capable of containing and treating the first one (1) inch of rainfall within the impervious area over a 48- to 72-hour period. In addition, the project team will communicate with the NCDEQ Department of Water Resources (DWR), which oversees nonpoint source planning, during the design and development of the SCM to demonstrate probable treatment capacity.

2 PE3 Project Proposed SGW Implementation

The intent of this section is to demonstrate the SGWs implementation for the PE3 project with preliminary design information and anticipated post construction activities. The first section provides an overview of the 60% design of the SGWs including the drainage basin areas, the number of proposed SGWs, and the SGW strata depths. Proposed treatment values based on case studies and regulatory guidance are included. The second section describes proposed post construction activities including the development of a landscaping plan and maintenance and inspection forms. There will also be a discussion on potential research opportunities and community outreach related to the PE3 project.

2.1 Preliminary Design Information

The RDU PE3 project involves the collection and treatment of 70 to 80 acres of expanded parking area stormwater runoff which includes the capture and treatment of some existing parking areas based on the geometric design. The runoff from this new built upon area (BUA) must be contained and treated by stormwater controls, which will be the SGWs. At the time of completion of the Stormwater Implementation Strategy, the 60% design included seven drainage basins with outfalls to seven SGWs (Figure 2).

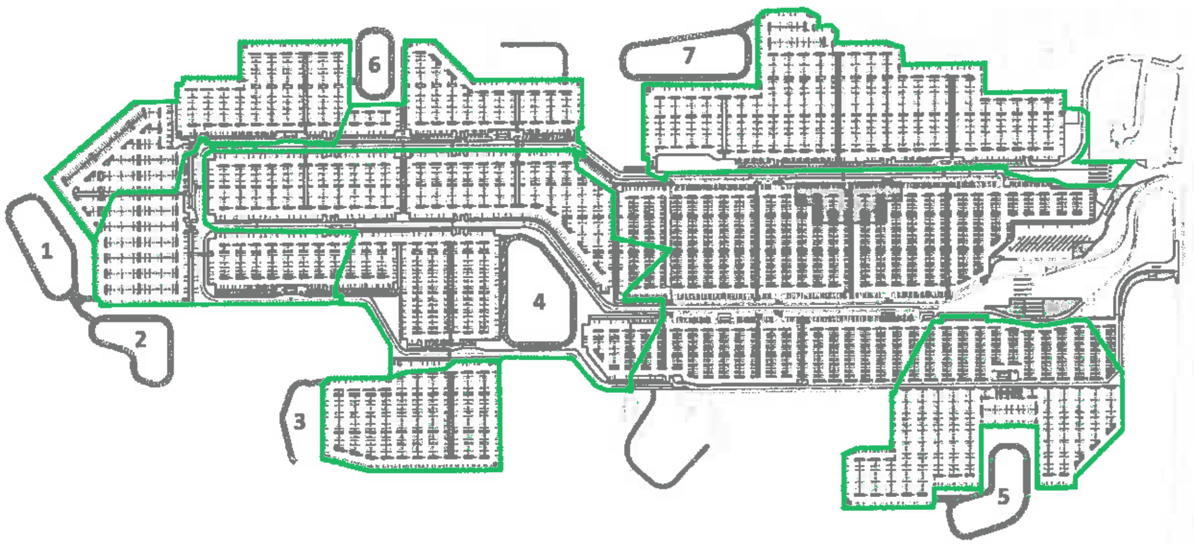

Figure 2: Drainage Areas for the RDU PE3 Project and Potential SGW Locations.

The drainage basins have the following approximate sizes:

- Basin 1 = 8.5 acres
- Basin 2 = 7.5 acres
- Basin 3 = 6.0 acres
- Basin 4 = 24.0 acres
- Basin 5 = 11.5 acres
- Basin 6 = 6.0 acres
- Basin 7 = 16.5 acres

The associated SGWs (numbered) are located adjacent to the corresponding drainage basin, but final sizing has not been determined.

Preliminary cross sections for the SGW follow the design guidance from the NCSU team who constructed the state's first SGW in Greensboro, the design specifications from the UNH Stormwater Center, and nearby state stormwater regulations including guidance published and referenced by the Maryland Department of the Environment, the Delaware Department of

Natural Resources and Environmental Control, and the Georgia Environmental Protection Division (Appendix A). Broadly, the SGWs for the RDU PE3 project will have a two-foot ponding depth and three main strata:

- 6 in wetland soil
- 6 in of choker stone, and
- 36 in of course gravel media (57 stone).

Each SGW will also have a sediment forebay, which will contain a portion of the runoff volume and remove much of the total suspended solids (TSS). The project team expects that treatment values for the SGW, based on the presumed design, should meet or exceed the effluent event mean concentration ($EMC_{Effluent}$) or median percent removal for the SGW constructed at Greensboro (Appendix A). Baseline treatment values that would be expected are 96% TSS removal, 54% total nitrogen (TN) removal, and 58% total phosphorus (TP) removal. In comparison, the NCDEQ standard for a bioretention cell is 35-40% TN removal and 45% TP removal (NCDEQ, 2018). The proposed treatment values are based on the findings from fully sized and studied SGWs at the UNH and informed by permitted projects, regulatory guidance from other states, and assumed design (Appendix A) (Houle & Ballestero, 2020).

2.2 Post Construction Activities

The project team is developing plans for landscaping and inspection and maintenance of the SGW to ensure proper function and success of the SCM. While those resources are not completed at the time of this report, the following sections outline the guidance from other states' regulatory agencies and departments of transportation (DOTs) that will guide the development of post construction activity planning documents. Additionally, post construction activities may include education and research campaigns related to this project in collaboration with local universities and partner organizations.

2.2.1 Landscaping

Landscaping is critical for the success of the SGWs due to plants' ability to remove pollutants and aid in the treatment of stormwater as it filters through the SCM. However, improper landscaping due to use of the wrong plants, improper timing of seeding, or inability for plants to establish, can impede the function of the SGW and lead to long term maintenance requirements. Notably, maintenance may be required if plant survivorship is particularly low after 1-2 years of the SGW construction. Replanting or adjustments to the planting plan (e.g., changing species mix) may be required to maintain the proper functioning of the SGW.

Most state guidance for SGWs recommends using native wetland plants and including a diversity of species (typically at least 3) (Atlanta Regional Commission, 2016) (MDOT State Highway Administration, 2022) (Maryland Department of the Environment, 2009). Specifically

Maine recommended *Juncus effusus, Typha latifolia,* and *Scirpus* species which are all non-invasive wetland species. Additionally, the City of Raleigh provided insights into their landscaping strategy and found that proper spacing, sequencing of plant installation, and avoiding last minute plant substitutions are critical for establishment of wetland plants (Dutra, 2023). This project will utilize landscaping and planting guidance from the NCDEQ Stormwater Design Manual for C-4 Stormwater Wetlands (NCDEQ, 2020). A North Carolina liscenced landscaping professional will be consulted to develop a landscaping plan.

2.2.2 Maintenance

While SGWs are less maintenance intensive over long time scales than bioretention cells and other SCMs, maintenance will be required in the first couple of years after construction to ensure proper drainage and function of the SGWs. After a year or two of being constructed, once wetland vegetation has established, the SGW should support natural hydrologic and ecologic processes. In comparison, bioretention cells are not as self-sustaining and require mulching activities 1-2 times a year and vegetation replacement periodically (Jarrett, 2022). SGWs are advantageous as they have less long-term maintenance requirements, and they allow the site to function more similarly to a natural wetland which provides other ecological benefits to the community and aligns with the sustainability goals of the RDUAA.

Most state guidance recommends conducting inspections after every major storm event (typically greater than 0.5 in) in the first year post construction (Maryland Department of the Environment, 2009) (Maine Department of Environmental Protection, 2016). During these inspections, recommended activities include:

- Verifying the system drains within 24-48 hours.
- Evaluating the condition of planted vegetation and conducting replanting if necessary.
- Identifying areas of erosion and making repairs.
- Checking inlets, outlets, and subdrains for proper functioning and cleaning out if necessary.

After the first year post construction, most state guidance recommends conducting inspections biannually. The following list of items may be indicators that additional controls or maintenance is needed:

- Evidence of standing water, discolored water, or accumulated sediments.
- Trash or debris
- Structural damage or blocked pipes
- Decaying vegetation
- Invasive species
- Trees and animal activity

Some states have provided Inspection, Operation, and Maintenance Guidance documents (Atlanta Regional Commission, 2016) (NHDOT, 2015). These documents will inform the maintenance plan developed by the project team.

2.2.3 Research and Community Outreach

The SGW project presents many opportunities for research and community education on the ecosystem services provided by wetlands. By implementing the project, researchers at NCSU and the NCDEQ may have opportunities to sample EMC influent values from the parking lot and effluent values from the SGW outfalls. Once performance data has been reviewed, the NCDEQ may be able to proceed with establishment of the SGW as a primary SCM, which will promote its use for future projects in the state.

The project also lends itself well to community outreach and education opportunities. Educational signage on the construction and design of the SGW, its purpose for treating stormwater, and the general importance of wetlands for improving water quality may be incorporated into the project site. These opportunities to educate the general public and create community partnerships is another goal of the RDUAA in its Sustainability Management Plan and helps promote a culture which values resilience and sustainability (Raleigh-Durham Airport Authority, 2023). It should be noted that the proposed SGWs for this project will provide large scale treatment for an area larger than any other previous SGW within the state of North Carolina.

3 SGW Case Studies

There have been numerous examples of designed and permitted SGWs in North Carolina and neighboring states in the Southeast and the Chesapeake Bay Watershed. Further, states such as Maryland, Delaware, and Georgia have developed regulatory guidance for SGWs, which promotes their implementation as a SCM in those states. The first section discusses the status of SGWs in North Carolina including case studies from the City of Greensboro, the City of Raleigh, and the North Carolina Department of Transportation (NCDOT) project. The second section describes permitted projects and state or local regulatory guidance for SGWs from Maryland, Delaware, and Georgia. The final section briefly discusses the regulatory guidance for SGWs beyond the study region in other eastern states. A summary of the design guidance from permitted projects and state regulatory guidance is provided in Appendix A.

3.1 Examples from North Carolina

Even though NCDEQ and other state agencies are still developing regulatory guidance for SGWs, three examples of SGWs have been designed and built in the state.

3.1.1 City of Greensboro

The predominant example of the SGW in North Carolina is located at 401 Patton Avenue and provides stormwater management for the City of Greensboro. The 14,365 square foot basin was sized to detain the 0.45 in storm from a 14-acre drainage area. Therefore, the SGW surface area was about 2.4% of the overall drainage area. Design included a wet forebay and one treatment cell with a bowl storage volume of 11,000 cubic feet where horizontal and vertical flow was used to filter the stormwater from the 89% impervious watershed. The SGW was designed with three layers: a 6 inch layer of wetland soil (100% sand), a 3.5 inch layer of choker stone (#78 Stone), and a 12 inch layer of gravel (#57 Stone). The SGW had a water quality ponding depth above the wetland surface of 1 foot and a maximum of 2.5 feet before the emergency spillway was activated. (Mitchell, Hunt, & Waickowski, 2021).

In the first year after construction, monitoring and inspection found that a layer of schmutzdecke had formed on the SGW surface. Raking was required to maintain proper hydrology and was completed twice during the first year after construction. After two years of operation, the hydraulic conductivity was reduced to 1.59 in/hour which is within the guidance for North Carolina of 1-2 inches/hour (Mitchell, Hunt, & Waickowski, 2021). If construction activities are timed with proper seeding and landscaping, there may be less risk of schmutzdecke accumulation.

Monitoring data was collected in the years after the SGW was constructed. Results are summarized in the table below.

Table 1: Comparison of Treatment Values between the Greensboro SGW and NCDEQ Standards for a Bioretention Cell with IWS (Mitchell, Hunt, & Waickowski, 2021) (NCDEQ, 2018)

Metric	Greensboro SGW	NCDEQ Bioretention Cell with IWS Standard
TN Median $EMC_{effluent}$	0.44 mg/L	0.58 mg/L
TP Median $EMC_{effluent}$	0.07 mg/L	0.12 mg/L
TN Percent Reduction	43%	35-40%
TP Percent Reduction	67%	45%

Table 1 shows that the Greensboro SGW median $EMC_{effluent}$ values for TN and TP were lower than the NCDEQ standard for a bioretention cell with IWS. Further, the Greensboro SGW median EMC percent reductions exceeded the NCDEQ standards for bioretention cells with IWS. These data show that the SGW performs equal to, and more often better than the bioretention cell with IWS.

Additionally, this SGW was undersized by a factor of 3 as it was only designed to contain a 0.45 in storm, as opposed to the 1 in storm regulatory requirement by NCDEQ (NCDEQ, 2018). Researchers at the UNH Stormwater Center have found that reductions in water quality volume (WQV) sizing impacts water quality performance and leads to lower rates of TSS, TN, and TP removal. Specifically, they found that a SGW designed to treat the 0.1 in storm (>90% reduction in WQV) had a TN percent removal that was 57% lower than would be expected for a conventional SGW. The difference in TP percent removal was less substantial, only 8% lower than would be expected (Houle & Ballestero, 2020). Therefore, it could be expected that with a fully sized unit, the TN and TP percent removals would have been higher in Greensboro if it had been fully sized.

3.1.2 City of Raleigh

In 2021, the City of Raleigh completed a $350,000 SGW green stormwater infrastructure project at the Walnut Creek Wetland Center, located in south Raleigh. The project was supported by NCDEQ who helped fund some of the construction costs and the educational components, which are still in development. The 5300 square foot wetland was designed to capture stormwater runoff from 1 acre of impervious surface, which included Peterson Street and other nearby streets, adjacent sidewalks, and buildings. Therefore, the SGW surface area was roughly 12.2% of the contributing drainage area (City of Raleigh, 2022)

The wetland is expected to substantially improve runoff water quality before it drains into Walnut Creek. The city published that the wetland could remove around 8 pounds of nitrogen and 135 pounds of suspended solids per year (City of Raleigh, 2022). Due to unforeseen issues with some of the drainage structures and the pipes, maintenance activities to ensure proper functioning of the SGW are ongoing, and the actual performance capabilities of the SGW are unknown at this time (Dutra, 2023).

3.1.3 NCDOT at Falls Lake

In North Carolina, NCDOT designed and constructed a SGW as a part of their stormwater BMP retrofit program. The SGW is located at the intersection of I-85 and Gate One Road near Falls Lake. The SGW was chosen for this project for several reasons. Since SGWs are known to be highly effective in treating stormwater runoff, this BMP maintains compliance with the Falls Lake Nutrient Strategy Rules. The high-water table at the site also favored the use of the SGW. Finally, the SGW has lower maintenance requirements and is a highly resilient BMP. This project was completed within the past year, but there is no monitoring data yet from the site. However, the site is highly accessible, and recent inspections have not found any signs of the schmutzdecke (Mullins, 2023) (McDaniel, 2023).

3.2 SGWs in the Study Region

Multiple neighboring states, which are biogeochemically and ecologically similar to North Carolina, in the southeastern United States and the Chesapeake Bay Watershed, have permitted SGW projects and published regulatory guidance on SGWs. These projects serve as additional proof of concept of the SGW and its utility as a stormwater control measure. This section describes SGW projects and adopted regulations in Maryland, Delaware, and Georgia.

3.2.1 Maryland

Maryland (MD) provides the best case study due to their extensive regulatory guidance and permitted SGW projects. The Maryland Department of the Environment (DOE) has recognized the utility of SGWs for stormwater management since at least 2009. In the 2009 revision of the Stormwater Design Manual, they defined a SGW as a nonstructural and micro-scale practice used to capture and treat stormwater runoff at the source from impervious areas less than one acre (Maryland Department of the Environment, 2009). However, they recognized that since the SGW requires the gravel substrate to remain saturated to support the wetland vegetation, the drainage area may be greater than one acre.

In 2012, the Maryland DOE published Stormwater Design Guidance specific to SGWs (Maryland Department of the Environment, 2012). The document describes that stormwater management regulations require environmental site design (ESD), which is composed of two main criteria. First, micro-scale practices such as SGWs provide pollutant treatment close to the source of runoff. Second, ESD practices must mimic natural hydrologic conditions. There is no drainage area requirement, but runoff controls should be distributed uniformly across the site and mimic local hydrology. In summary, ESD can treat equal or larger volumes of runoff compared to traditional stormwater BMPs, indicating that Maryland promotes utilizing practices such as SGWs in series to effectively manage stormwater. In 2018, the Maryland DOE released a fact sheet about SGWs as a Stormwater BMP with pollutant removal efficiencies (Maryland Department of the Environment, 2018).

In addition to guidance released from the Maryland DOE, the Maryland DOT and the City of Annapolis have published their own guidance for SGWs. The Maryland DOT State Highway Administration published design guidance drawings in 2022 for the SGW (MDOT State Highway Administration, 2022). These design guides include plan view, profile view, and detail drawings for the observation well and the stone or gabion basket weir. In addition, the City of Annapolis developed a Stormwater Maintenance Fact Sheet for SGWs that describes maintenance and monitoring activities for SGWs (City of Anapolis, n.d.).

Not only was Maryland a frontrunner for recognizing and using this control measure for managing stormwater, but they now have many examples of designed, permitted, and constructed SGWs throughout the state. One of the more publicized examples of a SGW in Maryland was the Graham Avenue Submerged Gravel Wetland project in Berlin, MD designed by EA Engineering (EA Engineering, Science, and Technology, n.d.). The purpose of the project was to alleviate flooding concerns and improve stormwater quality runoff. Construction began in 2019 and when completed, the basin provided 15,000 cubic feet of stormwater storage from a drainage area of 155,000 square feet or 3.55 acres of impervious area. Runoff drained primarily from heavily trafficked roadways and small commercial businesses and was filtered through the SGW before draining into the Hudson Branch Waterway (Town of Berlin, 2019). The design team published that nutrient load reductions included 165 pounds of nitrogen, 16 pounds of phosphorus, and 8400 pounds of TSS annually.

3.2.2 Delaware

Like Maryland, Delaware also has many examples of SGWs designed, permitted, and constructed in the state. In 2021, Delaware saw its first approved and permitted SGW in partnership with the Delaware Natural Resources and Environmental Control (DNREC) and the Kent Conservation District. Designed by Becker Morgan Group, the Kenton Dollar General Project was completed in 2021 and chose to use a SGW due to the site's high groundwater table and environmentally sensitive surrounding landscape (Delaware Business Times, 2021). The project received state acclaim and was recognized by the Governor's office with the Agricultural and Urban Conservation Award.

The Delaware DNREC considers SGWs a design variant of a constructed wetland (12-D) according to their BMP Standards and Specifications (DNREC, 2019). The agency has also released revised Post Construction Stormwater BMP Construction Review Checklists, which are currently out for public review. This new guidance includes user guides and checklists for submerged gravel wetlands (DNREC, 2023).

3.2.3 Georgia

The Atlanta Regional Commission, alongside the state Environmental Protection Division, the state Environmental Finance Authority, the Technical Advisory Group, and engineering consulting firms, developed the Georgia Stormwater Management Manual (Atlanta Regional Commission, 2016). Volume II of this document contains a Table of Key Considerations, Pollutant Removal Capabilities, Application and Site Feasibility Criteria, Planning and Design Criteria, Design Procedures, and Inspection and Maintenance Requirements for SGWs. The manual also contains an Operations and Guidance Document for SGWs, which describes routine maintenance activities and suggested schedules and includes an inspection form. The Georgia Environmental Protection Division refers to this manual under its sections on Coastal Stormwater, Municipal Stormwater, and the Georgia Water Planning Council. The Atlanta

Regional Council also developed a SGW Feasibility Checklist, which includes stormwater management credits, site feasibility, and site applicability (Atlanta Regional Commission, n.d.).

3.3 SGWs Outside the Study Region

SGWs have been used numerous times outside of the study region in other east coast states. In addition, many states have developed regulatory guidance as it pertains to SGWs. A table describing SGW regulatory guidance from Tennessee, New Jersey, West Virginia, and Maine is below. These examples provide further support of this SCM's capacity to adequately manage and treat stormwater.

Table 2: States outside of the Study Region with Regulatory Guidance on SGWs

State	Regulatory Guidance	Approach to SGWs
Tennessee	The Tennessee Department of Environment and Conservation, in collaboration with the University of Tennessee, developed the Tennessee Permanent Stormwater and Design Guidance Manual. Knox County developed a Stormwater Management Manual	SGW is a variation of a constructed wetland for stormwater treatment (Tennessee Stormwater Management, 2015). Section 4.4.3 of the Knox County Manual describes submerged gravel wetlands as a limited application stormwater BMP (Knox County Tennessee, 2008).
New Jersey	Stormwater BMP Manual: Subsurface Gravel Wetlands (NJ Department of Environmental Protection, 2021)	Requires a waiver or variance to address stormwater quality.
West Virginia	West Virginia Stormwater Management and Design Guidance Manual (West Virginia Department of Environmental Protection, 2012)	Identifies three basic design variations of stormwater wetlands: Wetland basin (Level 1), Multi-cell wetland or pond / wetland combination (Level 2), and Subsurface gravel wetland (Modified Level 2)
Maine	Stormwater BMPs (Maine Department of Environmental Protection, 2016) City of South Portland Stormwater Manual (City of South Portland, n.d.)	Chapter 7.4 – Gravel Wetlands in the Stormwater BMP Manual. The City of Portland manual includes Gravel Wetlands.

4 Conclusion

By utilizing SGWs, RDU is taking an innovative approach to stormwater management that is beyond the regulatory baseline and provides community benefits such as watershed conservation, visual enhancement, research opportunities, and education. To summarize, SGWs offer many benefits to airports since they drain quickly and should not have permanent standing water. Further, SGWs support the PE3 project at RDU since they function well in poorly draining soils and in areas where there is an impermeable layer. Since this SCM does not require infiltration, it is more feasible for a project of this scale. Additionally, the use of SGWs aligns with the RDUAA Sustainability Management Plan, which has created initiatives and targets for responsible stormwater and natural resources management and community outreach and collaboration. Through this project, the RDUAA demonstrates their commitment to sustainability and resiliency in the Neuse River Basin and to engagement with local communities and partners in the surrounding cities.

The SGW design will align with guidance from NCSU, UNH, and regulatory documents from surrounding states. Based on a presumptive approach and data from other projects, SGWs should treat the stormwater runoff from the PE3 lot equal to or potentially better than other approved SCMs in the state. Post construction activities will be necessary for maintaining proper function and treatment capacity of the SCM and will include landscaping and maintenance. The RDUAA may also collaborate with nearby research institutions and local partners to conduct research on the SGWs and develop signage and education opportunities for airport patrons and community members.

SGWs, while fairly new to North Carolina, are not a new concept and have been used extensively in other east coast states to improve water quality. In addition, other states such as Georgia, Maryland, Delaware, and others have developed regulatory guidance for the design and treatment capacity of SGWs. These projects and state stormwater guides prove that SGWs are an effective stormwater control. The success of this project may further demonstrate the effectiveness of this tool for future uses in North Carolina, and increased adoption of innovative SCMs such as SGWs will lead to better stormwater management throughout the state.

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Appendix A: SGW Design Guidance Summary

Table 3: Design Guidance from State Regulatory Agencies, Permitted Projects, and University Research. Sources: (Mitchell, Hunt, & Waickowski, 2021) (Atlanta Regional Commission, 2016) (Maryland Department of the Environment, 2009) (Maryland Department of the Environment, 2018) (DNREC, 2019) (Tennessee Stormwater Management, 2015) (Knox County Tennessee, 2008) (West Virginia Department of Environmental Protection, 2012) (NJ Department of Environmental Protection, 2021) (Maine Department of Environmental Protection, 2016) (UNH Stormwater Center, 2022) (Houle & Ballestero, 2020).

State	Number of Layer Strata	Wetland Soil (in)	Choker Stone (in)	Gravel (in)	Minimum Total Depth of SGW Layers (in)	Maximum Total Depth of SGW Layers (in)	Typical Ponding Depth (in)	Flood Elevation Ponding Depth (ft)	Drainage Area to SGW Ratio	Retention Time (hr)	TSS Percent Removal	TN Percent Removal	TP Percent Removal
North Carolina[1]	3	6	3.5	12	21.5		36	5	2.4%[2]		92%	43%	67%
North Carolina[3]													
Georgia	2	12		24-48	36	60			2-3%		80%	20%	50%
Maryland	1			24-48	24	48					80%	56%[4]	66%
Delaware	3	8	4	24-48	36		24				80%	30%	40%
Tennessee	1			24	24						80%	20%	60%
West Virginia	1			24	24						95%	95%[5]	55%
New Jersey	3	8	3	24	35		24				90%	90%	
Maine	3	8	6	24	38		18	3	5%	24-48			
New Hampshire[6]	3	8	3	24	35					24-30	96%	54%	58%

[1] Permitted project for the City of Greensboro.

[2] Calculated based on the project information and is not included in recommended guidance from NCSU.

[3] NCDOT is planning to publish guidance on the SGW in their BMP toolbox this year.

[4] As part of a larger system or treatment train.

[5] Only includes dissolved inorganic N.

[6] Design information is from the UNH Stormwater Center and is not approved guidance from the state.