Assessing the Feasibility of Green Stormwater Infrastructure Implementation in Downtown Durham

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INTRODUCTION

The city and county of Durham currently face water quality regulations with potential costs that far outpace the available resources to pay for them. Within the last three years, the North Carolina Department of Environment and Natural Resources (NC DENR) has issued two sets of nutrient management strategies, which mandate significant water quality improvements for Jordan and Falls Lakes. These strategies, known as the Jordan and Falls Lake Rules, seek to reduce the quantities of particular nutrients in the lakes' waters, namely phosphorus and nitrogen. Heightened levels of these nutrients create conditions in the lakes that threaten the safe use of their waters for recreation and as drinking water sources. Unfortunately for Durham, the city sits on watersheds for both of these lakes. Every parcel of land in the city contributes to water runoff into the lakes and thus the entire city is subject to these requirements. Preliminary estimates by Durham Stormwater Services on the costs of addressing these regulations range between $1.17 and $1.33 billion over the next twenty years (Cox 2008, 2012b). Not only is this a figure the city cannot afford, but Stormwater Services projects that these efforts will not even achieve the sought-after nutrient reduction targets contained in the rules (Cox 2012b), leaving the state and Durham searching for further answers at increasing costs.

The fiscal demands of these rules threaten the continued efforts to revitalize Durham as it transitions from its 20th century, tobacco-based economy. The downtown area in particular has emerged as a centerpiece for promoting an updated Durham that is a viable destination for new businesses. Efforts by the city, businesses, and local non-profits have directed $1.1 billion of public and private money towards reviving downtown Durham since the mid-1990s (Downtown Durham Inc., City of Durham, and Durham County 2008). Though the recession slowed this expansion, there are promising signs of re-emerging activity in the downtown area, with several new downtown businesses slated to open in the first several months of 2012 (Norton 2012). The requirements of the Jordan and Falls Lake Rules may compel the city to redirect hundreds of millions of dollars in local revenue to achieve compliance with the rules. This could threaten the economic progress of downtown Durham by siphoning away resources, which could be devoted to economic development. Not only this, but the city and county officials worry that paying for water quality measures may siphon resources away from provision of essential services to the city's poorer residents (Cummings 2011).

Emerging trends in stormwater management may offer a solution to this dilemma with an approach that combines relatively low capital costs with positive effects on water quality. The burgeoning movement of green stormwater infrastructure uses engineered elements to mimic natural systems of water absorption and filtration. Rather than expanding sewer systems and water treatment plants – traditional "gray" infrastructure elements – green stormwater infrastructure employs options that either collect and use the stormwater where it falls; slow the flow of stormwater before releasing it into gray infrastructure; or infiltrate the water on the spot, filtering out nutrients which impair water quality and directing the water into groundwater sources rather than funneling it through man-made channels.[1] European cities have applied this kind of infrastructure as far back as the late 1960s, when Germany and Austria were pioneering modern green roof designs (Dunnett and Kingsbury 2008). Municipalities in the US have begun to accept this framework over the last decade, with cities such as Chicago and Philadelphia reshaping their stormwater management plans around this new paradigm.

The main questions for this masters project, then, center around the applicability of green stormwater infrastructure to the situation in which Durham finds itself, with a focus on how this plan would interact with the economic development of downtown Durham. Therefore:

- Can a green stormwater infrastructure plan in downtown Durham address Durham's needs for stormwater nutrient reduction in a way that encourages continued economic development?
- What might such a stormwater plan look like in terms of the stakeholders involved, viable infrastructure to install, and means to finance or incentivize its implementation?

METHODOLOGY

To answer these questions I undertook a survey of the literature on green stormwater infrastructure implementation and effectiveness. I researched the history of Jordan and Falls Lake along with the development of the nutrient management strategies for both bodies of water. I examined best practices in U.S. cities that are considering and/or undertaking significant green stormwater infrastructure investments to address their own water quality issues. This research included attendance at conferences and forums in Durham and in Philadelphia that addressed various green stormwater elements and that were attended by various stormwater and development professionals.

Finally, I conducted twenty separate interviews with various local stakeholders to gain insight on the various perspectives towards local stormwater challenges. These stakeholders included Durham county and city officials, private developers owning downtown properties, non-profit environmental advocates, academic experts in water quality and green stormwater infrastructure, and green stormwater infrastructure producers and installers. A complete list of interviewees can be found in Appendix C.

Geographic Scope – Defining Downtown Durham

The Jordan and Falls Lake Rules affect watersheds which cover the entirety of the city of Durham as well as nearly all of Durham County. However, the scope of this analysis is concentrated on the downtown area of Durham, as requested by the client, Downtown

[1] A comparison of the phrase "green stormwater infrastructure" with similar terminology from the field is found in Appendix A. Appendix B provides a list of common green stormwater infrastructure options and briefly describes them.

Durham, Inc. (DDI). Solutions that are relevant to the larger Durham area may or may not be applicable to the downtown area itself. Therefore a working geographic definition is required to delineate the scope of downtown Durham for this report.

Two options are readily available for this definition. The first is the collection of downtown districts which the City Council and County Commission established in 1992 (Downtown Durham Inc., City of Durham, and Durham County 2008). These six districts – Brightleaf, American Tobacco, Government Services, City Center, Central Park, and Warehouse – comprise an area that covers roughly twelve blocks by fourteen blocks, or just over ¾ of a square mile (Downtown Durham Inc., City of Durham, and Durham County 2008). Alternatively, the Durham Planning Department created the Downtown Design Overlay (DDO) District in 2002, with subsequent amendments to expand it, most recently in 2010 (City of Durham 2010). While the DDO resembles the downtown districts created in 1992, it is slightly more expansive. Additionally, it is synonymous with the Downtown Tier, defined in the Unified Design Ordinance for the city. Given the benefits of aligning with official zoning boundaries, the Downtown Tier/Downtown Design Overlay District will be the relevant definition for this analysis.

PROBLEM STATEMENT

Background on Water Quality Regulation in the U.S.

The Jordan and Falls Lake Rules which Durham must now address have their roots in the Clean Water Act, passed by Congress in 1972. This act charged the EPA with "restoring and maintaining the chemical, physical, and biological integrity of the nation's waters," referring specifically to the country's surface waters: streams, rivers, and lakes (U.S. EPA 2008). While the act provided the EPA with some regulatory authority regarding water quality, most of the onus is placed on states to manage their own water bodies with the EPA acting in an oversight and funding capacity. States must classify each of their water bodies by the designated uses that the water source could support and report those designations to the EPA. Designated uses define whether the water body supplies drinking water, provides recreation opportunities, or supports various classes of wildlife.

An important aspect of designated uses is that any use which the lake could have supported since 1975 must be maintained, even if local communities have not historically taken advantage of that use. This requirement prevents states from simply downgrading designated uses to bring compromised water bodies back into compliance by setting them to lower standards (U.S. EPA 2008). Generally speaking, the minimum use to which a water body must abide is that it be both fishable and swimmable. States must also define the water quality standards that determine if a water body's uses are being safely met. These standards are preferably expressed in quantitative measures related to nutrient or sediment contents or pH levels. Multiple uses may overlap for any one body of water, such as providing both recreation opportunities and drinking water, but whichever use has the most stringent water quality standards sets the bar for the water source. The jurisdictions whose stormwater and treated wastewater feeds into these surface water bodies are responsible for maintaining the water quality standards, and state environmental regulatory bodies will hold local governments accountable to those standards.

When the metrics for a water body fall below the standards necessitated by its designated uses, a state must place the water body on its 303(d) list (named for the section of the act requiring this step) and report it to the EPA. The EPA then requires the state to develop a plan for bringing the water back into compliance with the standards required by its uses. This is the condition under which both Jordan and Falls Lake find themselves, and the rules developed by NC DENR are the EPA-mandated plans for restoring the necessary quality of the lakes' water. Based on state law, the Environmental Management Commission has quasi-judicial powers that it can exercise relating to violations of the lake rules. The enforcement options include civil penalties, which can go as high as $10,000 per month for a local government, along with criminal penalties and injunctive relief via the state Attorney General.

History of Jordan and Falls Lakes

Both Jordan and Falls Lake are man-made reservoirs, products of the Army Corps of Engineers. Jordan Lake formed in 1981 when the Corps completed a dam on the Haw River designed to control flooding downstream, provide a source of drinking water, and create water recreation opportunities (N.C. Division of Water Quality 2010; Vesilind 1998). Currently, Jordan Lake is the primary source of drinking water "for Cary, Apex, Morrisville, Northern Chatham, and the Wake County portion of Research Triangle Park" (North Carolina Conservation Network 2009). The Corps finished a second dam in 1983, this time on the Neuse River to create Falls Lake, with similar goals for flood control, recreation, and a steady drinking water supply to Raleigh, which had previously dealt with consistent water shortages (Steddum 2007). Falls Lake currently acts as the primary source for Raleigh's drinking water, "serving more than 450,000 people" (Wig 2010).

Even before the lakes were created, local governments and experts raised concerns about the quality of the water the lakes would contain. Assessments in the 1970s by water experts at Duke, UNC, and NC State, as well an analysis by an outside consultant, predicted that the New Hope arm of the two-pronged Jordan Lake would exhibit high phosphorus levels as soon as it formed (Vesilind 1998). As predicted, since 1983 the Division of Water Quality (DWQ) has rated the lake as eutrophic or hyper-eutrophic, indicating elevated levels of phosphorus and nitrogen which encourage algal blooms that damage water quality (N.C. Division of Water Quality 2010). Portions of Falls Lake have also exhibited elevated nutrient levels since the year of the lake's formation, also 1983 (Riechers 2011).

The levels of nitrogen and phosphorus in the waters are not problematic in and of themselves but rather because of the effects they have on plant life in the waters, particularly algae. When these nutrient levels are too high they promote the development of algal blooms in the waters which can have several impacts. The first is the depletion of oxygen levels in the waters; when fish populations in those waters cannot obtain sufficient oxygen, it leads to the dramatic and publicized instances of fish kills (N.C. Division of Water

Quality 2010). The algae also can cause unpleasant odors and tastes in the waters. These effects may require spending on water treatment plants by communities using the water source for drinking water, and they can impact the desirability of using the water body for recreational purposes (N.C. Division of Water Quality 2010). Finally, though less common, there are types of algae that can develop which release toxins in the water, making the water not just unpleasant to use or drink but harmful to users' health (Riechers 2011).

Just as the effects of phosphorus and nitrogen are indirect, the measure of their levels in the waters is indirect, and hence the standards associated with them are designed around proxies. In Falls and Jordan Lakes, the proxies are chlorophyll-a and pH levels. This methodology is well-established in North Carolina water quality regulations, dating back to the treatment of the Chowan River when it was designated as impaired in the 1970s (Gannon 2012b). The quantity of chlorophyll-a indicates the amount of active plant life in the water, reflecting the prevalence of living algae in a water body (Michaud 1994). PH is also impacted by the composition of plant life in the waters, as algae use hydrogen during photosynthesis. Larger concentrations of algae lead to decreases in hydrogen ions in the water and raise measures of pH (Michaud 1994).

Once the elevated chlorophyll-a and pH levels were detected by the state, Falls and Jordan Lake were classified as nutrient sensitive waters and placed on North Carolina's 303(d) list. This occurred in 2002 for Jordan Lake and 2008 for Falls, thus requiring the development of plans to bring the waters back into compliance with the water standards (North Carolina Conservation Network 2009; Ovaska 2010). The process of developing these rules took place throughout the 2000s, with extensive negotiations undertaken to determine the ideal mix of nitrogen and phosphorus in the lakes and to engage area jurisdictions in means of achieving those reductions. In particular, the Falls Lake Rules were crafted through extensive meetings between local stakeholders that were coordinated by the Triangle J Council of Governments. These stakeholder sessions resulted in a set of Consensus Principles that all municipalities surrounding the lake agreed upon and that were incorporated into the rules that were ultimately passed into law (Gannon 2012b).

Durham fought against being burdened with the bulk of the requirements for addressing the lakes' conditions, believing it was unfairly shouldering all the work of cleaning lakes that its residents use less than surrounding communities. While the rules for both lakes were in development, Durham officials voiced their concerns in public testimony and correspondence with NC DENR, citing the high costs of compliance and raising equity issues given Durham and much of its development existed prior to the lakes' creation (Bonfield 2010; Voorhees 2007, 2010). Though Durham residents can use the lakes for recreational purposes, the higher standards for drinking water supplies were driving the targets for lake quality improvement.

While certain allowances were granted to Durham, the resulting rules for the lakes still set aggressive goals for nutrient reduction that placed significant demands on Durham's stormwater management capabilities. By 2018, strategies must be in place to reduce phosphorus in the Upper New Hope Arm of Jordan Lake by 5% from its 2001 level along with a 35% reduction in nitrogen from the same baseline (Gannon 2012b). For Upper

Falls Lake, by a target of 2020, the sought-after nutrient reductions are 40% less nitrogen and 77% less phosphorus (Gannon 2012b). NC DENR established various deadlines for jurisdictions to submit their plans for achieving the sought-after reductions, with different plans required for new versus existing development.

Though Durham has drafted its initial strategies to meet state mandated nutrient reductions, these initiatives come with substantial price tags. Initial estimates predict that all of Durham's steps to limit nitrogen and phosphorus runoff would have costs totaling between $1.17 and $1.33 billion over a twenty year time period (Cox 2008, 2012b). To put this total in perspective, Durham's entire budget for FY 2011-2012 was only $362.5 million (City of Durham 2011a). Additionally, Durham Stormwater Services' annual budget is currently only $11.4 million (City of Durham Stormwater Services 2011). Clearly, the city cannot afford to enact all of the steps that the state may be requiring of it given current funding allocations. Furthermore, as Durham works through its projected options for nutrient reductions, it is forecasting steadily diminishing returns in the effectiveness of its options, so that mitigation efforts become increasingly less cost-effective (Cox 2012b).

Green Stormwater Infrastructure – An Emerging Stormwater Paradigm

As Durham looks to address its stormwater needs, it will naturally examine what other cities are doing in this regard. Other municipalities facing similar regulatory mandates based on the Clean Water Act have sought options that are outside of the traditional water treatment sphere. For much of the history of water management in the United States, the focus in urban areas has been on covering streams and rivers and replacing them with piped systems that funnel rain and wastewater to treatment facilities. There, contaminants can be flushed out before the water is then released back into the environment.

Such systems have run up against various limitations and have revealed their drawbacks as they have aged. First is the disruption such systems create in the natural waterways which are left intact. Gray infrastructure subverts the natural means and speeds by which rainwater travels from where it falls to the waterways it eventually reaches. Man-made systems lead to more extreme water flow speeds which either erode riverbeds or leave them dry and less able to support plant and animal life (Philadelphia Water Department 2011a). Furthermore, the water that flows through pipes and sewers is less filtered than that which infiltrates through soil layers. Infiltrated stormwater travels through underground channels to riverbeds and naturally loses chemicals and nutrients in the process.

In addition to the environmental drawbacks of gray infrastructure systems, there are significant costs involved with their expansion. These systems often require deep tunnels in urban areas to handle the increased flows of water; as more impervious surfaces are built in cities, more rainwater is diverted from soils into sewers. The scales of these systems lead to price tags in the billions of dollars and decades-long construction plans, such that there is no guarantee that their capacity will be sufficient for further growth when they are completed.

In certain areas, green stormwater infrastructure (GSI) has emerged as a compelling alternative to traditional stormwater management. GSI encompasses various options with the common goal of diverting water from gray infrastructure, filtering the water before it reaches sewers, or at the very least slowing the rainwater's speed of flow as it enters these systems to smooth out the demands on the gray infrastructure's capacity. In addition to helping to mimic more natural means of stormwater dispersal and thereby supporting a more balanced local ecology, GSI can be more cost-effective than gray infrastructure options. For instance, Milwaukee conducted a cost-effectiveness study which found that several GSI options were cheaper than gray infrastructure options when measured in dollars per gallon of water processed (Milwaukee Metropolitan Sewerage District 2009). Additionally, Philadelphia recently began a 25-year plan to address its stormwater needs primarily through GSI, and estimates it will save billions of dollars versus an alternative, purely gray infrastructure approach. The EPA has also estimated that Philadelphia saved $170 million between 2006 and 2009 by using GSI to minimize impacts on its sewer systems and thus reduce the funding required for sewer expansion and maintenance (U.S. EPA 2009)

Finally, along with hydrological and financial benefits, GSI can provide ancillary benefits that can further enhance projections of its economic impact. These benefits vary depending on the type of GSI being implemented. One example is green roofs, which usually consist of a four to six-inch thick growing medium placed on top of a traditional waterproof membrane, with minimal plant life to hold the medium in place. Such a system has several non-stormwater-related benefits. First, the layer of growth medium and plants can moderate the temperature on the roof, significantly combating the urban heat island effect. A Columbia University study of a green roof in New York observed reductions in winter heat losses of 34% while heat gains during summer months were lowered by 84% (Gaffin et al. 2010). Second, the presence of plant life on the roof creates a more pleasing environment and visual perspective for residents of that building and surrounding buildings, an effect which may raise property values. To date, hedonic modeling of the direct impact of green roofs on prices paid for properties has yet to be undertaken. For now researchers have been using studies on the effect of trees and parks on property values to estimate green roof impacts in this arena, with estimates of increases ranging from 4.5% to 11%, depending on the type of green roof (Phelps 2011). Finally, the presence of plant life in a place that would not normally support it provides a small amount of carbon sequestration, reducing GHG impacts. Even other, non-plant-based GSI elements can provide similar ancillary benefits; rainwater harvesting systems can take water that would normally flow into gray infrastructure and divert it to uses in the building such as toilet flushing, lowering water demand and providing savings in water use for the building owners.

THE APPLICABILITY OF GSI IN DURHAM

On first glance, GSI would seem like a natural fit to Durham's needs – a lower cost solution to stormwater quality that can provide additional benefits along with assisting the city's efforts to comply with the lake rules. However, further examination of the various GSI options reveals that there are reasons for and against their implementation in Durham, particularly in the downtown core. The issues raised by a closer look at GSI's applicability in Durham must be addressed before determining whether it is appropriate to develop and implement a comprehensive GSI plan for Durham.

GSI and the Lake Rules

The first difficulty in comparing other cities' commitment to GSI options in relation to Durham's needs relates to the specific regulatory requirements the different cities face. Philadelphia, Chicago, and Milwaukee are making significant GSI investments, with Philadelphia's commitment of $2 billion over the next 25 years the largest GSI commitment to date in the US (Philadelphia Water Department 2011a). In those cities, GSI is being implemented to reduce instances of combined sewer overflows (CSOs). In those jurisdictions, parts of the city channel stormwater and wastewater flows into a combined system. Normally this mix of waste and rainwater is sent to water treatment plants for processing before being released back into the environment. However, during heavy rain events the level of stormwater exceeds the systems' capacities. In these instances, pressure on the system must be released by expelling some unprocessed waste and rainwater into natural waterways. This is the primary source of diminished water quality in these areas, and thus the focus is on lowering the volume of water entering gray infrastructure to minimize CSOs. This allows these jurisdictions to focus on more basic metrics for GSI performance and broadens the range of options that are feasible.

In Durham's case, the focus is on reducing the levels of nitrogen and phosphorus. This complicates the possibility of a GSI solution in two ways. First, there is considerable uncertainty surrounding the exact sources of the nitrogen and phosphorus flowing into the two lakes. Some potential sources, such as fertilizers, are obvious and efforts are underway to address those. The county, through the Durham Soil and Water Conservation District, is largely leading this work. With their jurisdiction including property outside the city, the District has worked with farmers to find ways to mitigate their fertilizer use (Dupree 2012). In addition, the District has provided educational materials to Durham city residents on proper use of fertilizers, including the amount to be applied and when, based on the type of grass on a property (Durham Soil and Water Conservation District 2011).

Beyond these sources, questions remain as to the origin of specific nutrients, and thus it is unclear where GSI should be incorporated to best address those inputs. With CSOs, the source of contaminated water is clearer and such specificity of GSI implementation is not necessary. Since Durham must reduce specific nutrients in its waters, they require more precise models of those nutrients' origins, which have not yet been developed. These concerns are being investigated by the Nutrient Science Advisory

Board (NSAB), a collection of water quality experts and stakeholders that the General Assembly created during the codification of the Falls Lake Rules. Among the questions the NSAB has raised are the degree of atmospheric deposition of nitrogen and phosphorus, along with how to model the pathway of those nutrients through the watershed, including their introduction and transport through the area until they reach the lakes (D'Arconte 2012). The NSAB is currently working with DWQ to create contract proposals for third party modeling firms to draft more precise estimates of nutrient load allocations, with contracts due to be awarded and modeling work begun by late summer 2012 (Gannon 2012a).

Secondly, the focus on nitrogen and phosphorus reduction means that the state is currently only crediting those GSI options which directly reduce those nutrients, rather than those which only reduce water flows into gray infrastructure. Thus, a GSI option like a green roof does not receive credit from the state for addressing the lake rules. Green roofs may even contribute *additional* nitrogen and phosphorus to the lakes since they require a minimal amount of fertilization after installation for their plants to take hold. Thus the GSI options for Durham are limited if they follow the state's current system of crediting approaches to the lake rules. Stormwater Services staff have confirmed that the GSI methods they will consider for implementation are restricted to those that the state will give credit for based on nutrient reduction, and that Durham is working with NC DENR to expand the "toolbox" to include additional GSI options that have scientific backing for their performance (Cox 2012c). To date, NC DENR does not have a clear set of performance or data collection standards that a GSI option must meet before it will be certified by the state. Rich Gannon with DWQ has acknowledged that creating such standards would provide clarity and reassurance to communities that additional data collection could help expand the credited GSI options; an outline of that GSI approval process will likely be prepared by July 2012, while a comprehensive review system may not be complete until July 2013 (Gannon 2012a).

Additional aspects of the lake rules complicate efforts to apply GSI best practices from other cities to Durham. The timelines of the rules vary from six to eight years for Durham to reach certain benchmarks. If those benchmarks are not met, more stringent requirements from the state will kick in. These looming deadlines are prompting Durham stormwater staff to be intently focused on predictable short-term gains. In contrast, Philadelphia gained approval from the Pennsylvania Department of Environmental Protection for a 25-year plan for implementing GSI. This provides Philadelphia with much more leeway relative to Durham in terms of the amount of time available for realizing GSI's benefits.

GSI and Durham's Soils

As previously mentioned, the emphasis in the lake rules on nutrient reduction highlights certain GSI options over others. Concurrently, the state has estimated that GSI options that incorporate infiltration will have larger benefits and thus receive more credit. These benefits have been incorporated into the Jordan/Falls Lake Stormwater Load

Accounting Tool, a modeling tool designed by NC State researches and NC DENR (NC DENR and NC State University 2011). This tool, provided to municipalities in Excel file format, allows users to input data on GSI characteristics and receive the estimated impacts of those options, based on current GSI performance data. Infiltration has been shown to provide the greatest benefits in nitrogen and phosphorus reduction, as the soils act as filters to collect the nutrients before releasing the water into natural systems.

Durham's particular soils present challenges to incorporating a significant amount of infiltration options. Durham is situated in the Triassic Basin and thus rests on thick clay soils, classified as Grade "D" (Wilbur and Wiebke 2012). These denser soils do not preclude infiltration altogether, but they make that process much slower. Hence, green infrastructure designed for infiltration may lead to soils around that piece of infrastructure storing greater amounts of water, leading to rising water tables (Dreps 2012). Chris Dreps, Executive Director of the Ellerbe Creek Watershed Association (ECWA), has seen this consequence firsthand, observing improperly installed infiltration options at residential properties that created high water table issues for the owner. With these soils, Dreps contends that it is "not a matter of infiltration," but rather one of dealing with the greater levels of storage of water by soils absorbing green infrastructure intake (Dreps 2012).

This is not to say that infiltration options such as rain gardens or bioswales are entirely untenable in Durham. It does mean that greater attention to detail is required in the application and engineering of the GSI than would be necessary in areas with looser soils. In particular, these options must be installed in ways that do not overly saturate the soils around properties. It may also mean that certain sites must be deemed suitable to water storage options, such as cisterns, but not infiltration, or that infiltration and storage GSI must be interconnected on a site to be effective. This may turn out to be the case in the downtown core, where saturated soils would also present a particular concern. Dr. Bill Hunt at NC State University recommends against intensive infiltration implementation in the downtown area, where the denser collection of building footprints could be threatened by the lower stability provided by water-saturated soils (Hunt 2012).

GSI and Durham's Climate

In addition to Durham's conditions on the ground, there are particular conditions of Durham in the air that provide issues for certain GSI options. Examining the option of green roofs shows that several factors have to be weighed when considering how a GSI option will perform in Durham and how to value those performance levels.

Predicting the potential performance and health of green roofs in Durham requires evaluation of the local climate. In terms of precipitation, the North Carolina climate provides a suitable environment for green roof health. Precipitation levels are relatively steady throughout the year, and this more constant level of natural irrigation reduces maintenance needs for green roof plants that tend to be hardy but still benefit from predictable levels of moisture (Hunt 2012). However, the temperatures during North Carolina summers hamper green roof plant coverage. Dr. Hunt has found in his research that in summer months evening temperatures do not drop enough from daytime temperatures for green roof plants to fully recover from the day time heat (Hunt 2012). This stress on the plants reduces the amount of coverage they can achieve on the roof and thus potentially minimizes the benefits provided by this GSI.

However, it may be possible to address the concerns of lower plant coverage raised by Dr. Hunt through different green roof designs. In 2008, Duke Hospital installed a green roof on its entrance building that has seen successful growth and full coverage by its plant base since installation. This is at least partially thanks to an irrigation system that was installed along with the growing medium and plants, allowing for additional watering when necessary. According to Tim Pennigar, the coordinator for Medical Center maintenance and construction, the irrigation schedule provided by the installer, Xero Flor, has been an accurate guide for supporting full plant coverage (Pennigar 2012). Interestingly, in Pennigar's own experience, there have been ancillary benefits from the green roof but not the same ones as advertised. He has observed little impact on the energy use of the building from the projected stabilization of roof temperatures, yet he and other hospital staff do value the inclusion of additional green scenery for patients and the beneficial effects that has on visitors' stress levels (Pennigar 2012).

GSI and the Downtown Durham Building Stock

When looking specifically at the downtown Durham area, any plans for GSI implementation will naturally have to take account of the existing infrastructure and building stock. The significant number of warehouses and office buildings with flat roofs suggests that green roofs would be an opportune fit. When applying green roofs to existing buildings, engineering assessments are required to determine the load-bearing capacity of the roofs. Green roofs will apply weights not originally anticipated on those roofs, especially since they will retain water and snow that normally would be siphoned off as quickly as possible. Thus roofs must generally be able to withstand an additional 15-20 pounds per square foot when incorporating green roof elements (Rugh 2012). The city does not currently have data on the general load-bearing capacity of Durham buildings, and engineering assessments will be a necessary component of a GSI analysis in the area. Fortunately, such assessments do not present a significant cost and should not be a major impediment to green roof application.

The dense development of the downtown core precludes GSI options that take up significant open space. However, GSI options can be incorporated in public areas with the proper planning and implementation. The city is currently developing an Urban Open Space plan, and while the Planning Department may not be currently envisioning GSI options in that plan, the Stormwater Division could work with them to find ways to incorporate GSI elements (Wilbur and Wiebke 2012). These types of GSI elements tend to be infiltration focused, and as previously mentioned such options would have to be carefully designed. One option for incorporating such GSI is to focus on filtration over infiltration. Bill Hunt envisions GSI options like planter boxes that are more liberally incorporated into open spaces and are designed to filter water, but then direct it to gray infrastructure rather than soil substrates, as would typically be done (Hunt 2012). This kind of modification allows Durham to maximize GSI options into the existing open space of the downtown area while attuning it to the city's soil and infrastructure conditions.

GSI and Available Funding

The appeal of GSI for the cities that have committed to its use are its lower average costs over the life of the infrastructure. A decentralized approach to the management of stormwater allows stormwater agencies to be more adaptive. They can address their water systems in smaller increments rather than undertake significant public works projects with long time horizons and higher potential for delays or cost overruns. GSI options still have costs, though, especially when the city is evaluating the options before it. Durham has begun pilots of GSI options to measure its effectiveness in the city's particular climate and ecology, and these measurement efforts increase the costs of standard GSI installation.

Furthermore, GSI options that are additions to traditional infrastructure elements, such as green roofs, will have higher upfront costs with the promise that they will pay off in the long run. As a rule of thumb, green roofs costs roughly twice as much per square foot as conventional roofs, but when installed properly they can double the life of the waterproof membrane underneath them by protecting that layer from damage caused by UV rays. Since extended roof life and higher costs roughly cancel each other out, it is the energy savings and property value increases associated with green roofs that allow them to eventually pay for themselves. However, that payoff requires an owner who will be with the building long enough to see the benefits. Those owners tend to be public authorities, which are more likely to maintain ownership of the same building for extended periods of time. Hence private owners are less likely to invest in green roofs unless provided an incentive that accrues earlier in the life of the roof. One potential option to incentivize green roofs or other GSI incorporation by private owners would be a credit on stormwater fees to offset installation costs. However, the city is unlikely to provide such a credit when the state does not also recognize the impact of the GSI, meaning options like green roofs are unlikely to receive much local financial support.

In addition to these factors, general funding for stormwater and clean water management is declining at the state and federal level. Some of these impacts are due to budget cutting by the current General Assembly. With the passage of the biennial budget in 2011, the GA reduced funding for the Department of Environment and Natural Resources for FY 2011-12 by approximately $15.5 million, an 8.5% decrease, and they imposed an additional 10.6% reduction in funding for FY 2012-13 (Fiscal Research Division 2012). The budget decrease for NC DENR has led DWQ to use some of the 319 grant money given to them by the EPA for operating expenses, lowering the amount available for DWQ to provide to local jurisdictions (Dupree 2012). Furthermore, funding has fallen in recent years for the Clean Water and Drinking Water State Revolving Loan Funds (SRFs), two important sources of funding to local projects to improve water quality. The SRFs are funded primarily through EPA allocations, which are then disbursed to the states with a requirement for a 20% match of the federal amount. This money is then used to finance low-interest loans to local governments to finance water treatment projects. The amounts granted to the EPA for the SRFs have declined from a peak of $3.78 billion in FY 2010 to $2.49 billion in FY 2011, $2.38 billion in FY 2012 and a projected $2.03 billion in FY 2013 (Keeley 2011; U.S. EPA 2012a). Less money from Washington will lead to a lower match from North Carolina and reduced available funding for North Carolina jurisdictions. Additionally, as federal matching amounts have fallen, North Carolina has reduced the amount that is set aside for green projects, which can include BMPs targeted at stormwater. 20% of available funds were reserved for such projects in FY 2011, but this fell to 10% in FY 2012 (NC DENR 2011, 2012). Clearly such funds would apply to GSI efforts to address the lake rules, and the smaller pot of available money for this option has left local officials searching for other sources of revenue to fund their efforts.

No matter the economic climate, Durham would conceivably seek to employ the most cost-effective plans to address their stormwater needs. The limited resources available from state and federal sources make it even more imperative that Durham identifies the stormwater solutions that will deliver the most impact per dollar spent. This goal has been confirmed in public and private communications by Durham stormwater staff (Cox 2012a, 2012c). The metric by which the city is examining the effectiveness of GSI, along with their other options for addressing the lake rules, is dollars per pound of nitrogen or phosphorus mitigated. They are also assuming an average life span of each piece of infrastructure of thirty years, and calculated a total cost that includes the initial capital outlay combined with discounted thirty-year maintenance costs (Cox 2012c).

Durham has largely relied on outside consultants to conduct the cost-effectiveness analyses, and the results thus far have been hard to generalize. In the Watershed Improvement Plan that was designed for Durham by the consulting firm Brown and Caldwell, only large-scale BMPs were given explicit figures for dollars per pound of nutrient mitigation (Brown & Caldwell 2010). Smaller scale interventions that included common GSI options were modeled for their reduction of overall stormwater flows, but no analysis of nutrient reduction in relation to their costs was provided in the report. Dr. Bill Hunt provided more detailed cost-effectiveness information in an evaluation of part of the Third Ford Creek watershed, which flows into Jordan Lake. By constructing a thorough analysis of current land uses and modeling the appropriate GSI options in those areas, Dr. Hunt graphed cost-effectiveness curves, showing which interventions provided the most nutrient reduction per cost. While the results varied slightly across seven other watersheds that Dr. Hunt also examined, but several GSI options consistently ranked better in cost-effectiveness: disconnecting downspouts, bioretention, and stormwater wetlands (Hunt, Hatch, and DeBusk 2011). Dr. Hunt also observed increasing returns to scale from the GSI and recommended that the city incorporate fewer, larger stormwater management options (Hunt, Hatch, and DeBusk 2011). Applying these large-scale options in the downtown area of Durham would prove challenging given the density of the built environment and the growing value of the land there as development and construction continue.

Problem Summary

The particular conditions in Durham – regulatory, physical, hydrological, and financial – all complicate the application of GSI in this area. While other cities have moved to embrace this new field of stormwater management, Durham's situation presents challenges to applying the best practices learned elsewhere. Fundamental questions remain for policy makers, including from where nitrogen and phosphorus are originating, how they travel to the lakes, how those pathways vary with rainfall amounts and seasonal changes, and how to adapt GSI to account for these factors. The Triassic Basin soils of the region complicate the installation of those GSI options which would best address the lake rules, while other alternatives, such as green roofs, can work in this climate but do not assist with lake rule compliance. Finally, in a time of severely constrained public finances, there are questions of how to promote the adoption of GSI by private landowners. Little funding is available to either subsidize costs or to undertake substantial public expenditure and installation to stimulate the GSI market.

With those limitations in mind, the following alternatives are presented as options for moving GSI implementation closer to feasibility. These alternatives represent a distillation of best practices and innovative solutions that emerged in the course of interviews and research. While no alternative presents a ready solution to the problems highlighted above, they represent potential avenues for clarifying how GSI may feasibly assist Durham in achieving its stormwater goals.

EVALUATION OF POTENTIAL ALTERNATIVES

1) Produce a district-level or building-level audit of downtown Durham and target the appropriate GSI investments to specific districts or building types.

Given the challenges which Durham's soils present and the specific nutrient reduction demands of the lake rules, the city needs a detailed projection of which GSI elements would be best suited for each parcel of city land. The low infiltration capacity of Durham soils requires the careful selection and placement of GSI to ensure that structures are not compromised by raised water tables, as highlighted by Mr. Dreps and Dr. Hunt. To start conceptualizing GSI implementation, a complete audit of downtown Durham's built environment, combined with its underlying soil structure and topography, would help develop a model of what the city could reasonably implement and where.

The Ellerbe Creek Watershed Association (ECWA) has recently applied for EPA grants to allow it to do just such an audit for a selected part of Durham. ECWA proposes to conduct a process developed by the Center for Watershed Protection called a Unified Subwatershed and Site Reconnaissance Plan. This plan calls for collecting data on building types and their distribution, cataloguing impervious surfaces, and identifying the location of sewer drains and gray infrastructure systems (Wright et al. 2005). The resulting information would provide a map of the watershed that would allow Stormwater Services to target GSI elements to obtain the largest impact in nutrient reduction while protecting the structural integrity of surrounding buildings from saturated soils.

ECWA's grant request includes a budget of just under $66,000 to complete the Unified Subwatershed and Site Reconnaissance Plan on roughly one-third of the Ellerbe Creek watershed. The project is focused on the "most urbanized" areas of the watershed, including the catchments which overlap with downtown Durham (Ellerbe Creek Watershed Association 2012). The proposal's cost also includes the analysis of the resulting data and communicating results to residents and policymakers. Extrapolating this kind of analysis to the rest of the downtown area (which inhabits the Third Fork Creek watershed flowing into Jordan Lake) could be done for minimal costs. This option would help the city obtain a clear inventory of the interlocking systems that will be affected by GSI. From this information, the city could assess where GSI would be best implemented, and thus what affects GSI could have towards the city reaching its lake rules goals.

2) Increase local stormwater management fees and provide adequate credits for GSI implementation to incentivize owners to adopt GSI options.

Assuming that GSI compares well to gray infrastructure on measures of cost-effectiveness, funding will still be required for construction of GSI options. The aforementioned sources of available funding are dwindling, following the general trend of diminishing resources from the federal government placing revenue-raising pressure on state and local governments. While Durham can seek to leverage available funding options as much as they can through 319 grants and the Clean Drinking Water Trust Fund, these limited and decreasing resources will not be sufficient for Durham's GSI needs. Thus, the city itself must seek to raise additional funds, and one option is through increased stormwater service fees.

However, as recently as May 2011 the City Council approved increased stormwater fees, raising rates by an average of 8.5% for all customers (City of Durham 2011b). Additionally, Durham voters passed two sales tax increases in November 2011 to raise additional revenue for transit and education investments (Hartness and Mims 2011). This is not to say that no space remains for higher fees, as some households may see minimal impacts from these new charges. For instance, with the stormwater fee increase, the three tiers of residential billing customers would only pay an additional $2.40 to $10.08 per year (City of Durham Stormwater Services 2011). Furthermore, Durham's stormwater fees are near the median for comparable jurisdictions in North Carolina and Virginia (City of Durham Stormwater Services 2011)

It is highly unlikely that the city could raise sufficient revenue to address all of the lake rules requirements simply by raising stormwater fees. Projections by Stormwater Services for the rate increases necessary to comply with the Jordan Lake Rules show increases of 670% for customers in that watershed (Cox 2008). However, the city could modify the fee structure to pay for some additional infrastructure to address the lake rules while incentivizing GSI implementation by property owners. This could be achieved with a combination of an increase in billing rates matched with a crediting system to allow for customers to mitigate their stormwater fees through incorporating GSI. Currently the only means for a customer to reduce their rate is through the reduction of actual impervious surfaces on their property, which could conceivably only be achieved by removing driveways and sidewalks. A credit system would reduce rates based on the implementation of GSI that would provide benefits in stormwater impacts sought after by the city. Furthermore, the Durham stormwater ordinance already contains language allowing for a credit system to be put in place, but the city has yet to adopt one.

Such a system is what Philadelphia is implementing in concordance with their combined sewer overflow plan. Their rate structure now provides credits for increases in "greened acres," lowering rates as owners increase the amount of rainwater that their property can manage before it overflows into gray infrastructure (Philadelphia Water Department 2011a). Durham could implement a similar system, while being certain to credit only those GSI options which they were comfortable having private owners, install. Since infiltration-based GSI requires significant design oversight when placed in Durham's soils, the city may want to limit crediting to those options that are less prone to disrupting water table levels. These options would include storage-based GSI, such as green roofs and cisterns.

The development of these incentives will require careful attention to detail to ensure that only those practices most beneficial to Durham are encouraged. For instance, research conducted by Michigan State University found, perhaps not surprisingly, that roofs with lower slopes were better able to retain stormwater than steeper roofs. Roofs with a 2% incline on average retained 10% more rainwater than those with a 25% slant (Getter, Rowe, and Andresen 2007). Examples such as this show how the city could apply the science of GSI when constructing incentives that promote installations where the city could obtain the most value, in this case by providing more credit to roofs placed where slopes are lower.

3) Adopt mandates to require the inclusion of GSI in the construction or refurbishment of public buildings.

The city can certainly take the appropriate steps to incentivize the adoption of GSI by private landowners in the downtown area. In addition to those steps, the city could have a significant effect on GSI feasibility in the area by requiring the adoption of GSI in municipally owned buildings. With a significant percentage of property in downtown Durham owned by the city itself, such a step would more than purely symbolic. As a primary property owner of downtown properties, the city must be involved in the incorporation of GSI in that area to have a significant impact on green stormwater water management efforts.

Having the city commit to GSI options makes sense from an investment standpoint as well since several of the options currently available have long payback periods that are more appropriate for long-term lease holders such as the city. Private developers are unlikely to consider investments with extended payback timelines. Michael Goodmon of Capitol Broadcasting cited a ten-year payback period for infrastructure investments as generally the longest his company will consider, while something between ten and fifteen years may be interesting but probably unfeasible (Goodmon 2012). To compare with a GSI example, green roofs are consistently estimated to pay off their initial cost over their lifespan, but this can take between thirty-five and fifty years (Porsche and Köhler 2003). Such an investment would be more reasonable for the city itself given the higher likelihood of Durham maintaining ownership of their current building stock.

Making such a commitment also sends strong signals to the overall GSI market and provides a sure customer to GSI producers looking to make investments in the area. When Chicago implemented its Green Alley pilot program, they observed significant decreases in costs within the first several months. For example, the cost of permeable concrete, one of the options being tested for the green alleys, fell by approximately 70% within a six month span (Attarian 2010). Other aspects of the projects which were more expensive than traditional alley paving, such as increased labor costs due to unfamiliarity with new processes, would conceivably fall over longer time horizons as contractors learned these paving techniques. Similarly, creating a market for GSI in the Durham area would encourage the development of more GSI installation companies and increase the likelihood of a competitive market to reduce overall GSI prices. This could further improve the chance of GSI implementation by private landowners as GSI costs drop and payback periods for those investments decrease.

4) Develop a new Durham city oversight committee that coordinates the efforts of the water management, transportation, economic development, and planning departments to address cross-jurisdictional issues and ensure alignment of priorities.

One of the key insights from other cities' best practices with GSI is the recognition of the inter-departmental impacts of addressing stormwater issues in a sustainable manner. It is not an issue that can be addressed by Stormwater Services alone. Currently they can only address the management of the water once it reaches the gray infrastructure of the city. However, a GSI approach relies on coordination between all the departments which are responsible for how the city's buildings are maintained and how its lands are used.

Therefore, some measure of integration is required between the departments necessary for GSI implementation to ensure that efforts are coordinated towards the common goal of sustainable stormwater management. Other departments might not be specifically opposed to GSI, but may simply be ignorant of its purpose and how it can be integrated into their own practices. Stormwater Services already has created the links with departments that have obvious stormwater impacts, such as with the Parks Department to assist with GSI construction or establishing stream buffers in city parks (Wilbur and Wiebke 2012). The vision of GSI requires a broader perspective on partnerships with city departments. For instance, the Department of Public Works and Department of Transportation must be made aware of how to better design and implement streetscape improvements to install efficient GSI elements. The General Services department, which manages the city's building stock, must be educated on the benefits of GSI retrofitting and the proper ways to maintain such infrastructure. The Planning Department must understand the stormwater water impacts of developments and recognize on their own opportunities for GSI implementation to mitigate the effects of new construction.

The alignment of practices among the different departments would be best handled in the short term by a task force consisting of representatives from the affected departments. If GSI implementation reached a sufficient scale, then the city could consider hiring full-time employees in each department to focus solely or primarily on the GSI efforts under each department's umbrella. For now, a concerted effort at communicating the value of GSI to staff who are unfamiliar with it is a necessary first step to increasing awareness of stormwater impacts in city departments which currently see stormwater as outside their purview. The city managers' office seems to be the proper nexus for creating and maintaining such a task force, with co-direction or close coordination with stormwater services to provide the relevant data and expertise. If nothing else, a representative from the managers' office should take charge of the issue and handle the dissemination of GSI and stormwater management information to the affected Durham city departments.

5) Construct a public/private partnership with local developers to provide public seed investments to stimulate private spending on GSI.

Partnerships between the city and outside actors are a likely prerequisite for widespread GSI implementation, as evidenced by the experience of other U.S. cities in this field. Philadelphia has cited their extensive interaction with local community groups and watershed protection associations in conducting outreach and education efforts on GSI, highlighting these efforts as laying the foundation for broader GSI acceptance (Cammarata 2011; Philadelphia Water Department 2011a). Washington, D.C. has created similar partnerships and has taken some of them even further. DC Greenworks is a not-for-profit organization that is the city's agent for green roof subsidization and installation assistance. While D.C. is involved in and passionate about GSI implementation, it has thus far contracted out the work in the field to install GSI, relegating itself to funding and inspection roles (Barger 2012).

The justification for such an approach would be to improve efficiency and lower the city's involvement in direct GSI installation. The decentralization of GSI is one of its potential advantages over capital-intensive gray infrastructure, and the decentralized nature makes GSI less amenable to control by a city agency. With the current rules' timelines, though, this may be a difficult position for Durham Stormwater Services to accept. The looming intermediate deadlines in the phased timeline of the rules will require visible progress by the city in a matter of a few years. Given this short time horizon, the city may be less willing to cede control of GSI implementation to another party. Instead, the city is likely to work with outside organizations, such as the Ellerbe Creek Watershed Association, on small pilot programs and as educational outreach providers, rather than as primary contacts for and implementers of GSI.

6) Incorporate funding for GSI within the creation of a downtown business improvement district (BID).

One of Downtown Durham, Inc.'s other projects is the creation of a business improvement district (BID) for the downtown area. There is the potential to incorporate GSI support into the operations of the Downtown Durham BID, and to use some of the BID's proceeds to fund GSI activities. This would provide an alternative funding mechanism to the further increase of stormwater fees by the city or the chasing of shrinking state and federal funding for GSI implementation.

However, given that the BID has been under development for an extended period of time, it is likely that much of the proposed revenue has already had uses designated. It would be difficult to obtain much of the proposed BID revenue for GSI incorporation, especially if property owners in the BID saw little collective benefit. The security and streetscape enhancement efforts common to most BIDs have clear spillover effects for all participating businesses. Unless downtown Durham companies were able to share in whatever positive effects could be gained from GSI implementation, then there would likely be little support for the use of funds for this purpose.

A potential avenue GSI proponents could promote to BID participants in support of GSI investments would be the branding value of demonstrating Durham's green commitment. The image of Durham as a progressively green community, with buildings incorporating cutting edge green stormwater management, could have a value to prospective tenants that would eventually translate into higher property values and rent revenue. Paving the way for GSI could then be seen as an investment in a green Durham brand. Though owners may not feel inclined to increase funding to the point of complete GSI construction, smaller but still relevant spending could be supported that will make a real difference towards GSI feasibility. One such option would be engineering evaluations of the roof capacity of the downtown building stock. Such evaluations typically cost a few thousand dollars per building but are necessary to confirm if the building can support a green roof and its added weight. Providing a fund for interested property owners to pay for such evaluations would demonstrate interest in GSI without requiring significant use of BID revenue.

7) Continue lobbying efforts with the state to approve the use more GSI options and to provide more credit for the options that encourage innovative stormwater management.

Durham has made it clear to state and federal regulators that it needs a larger palette of options to address the nutrient levels of the stormwater from its watersheds. In a presentation to Ellen Gilinsky of the EPA, John Cox from Durham Stormwater Services used the analogy of bringing a "knife to a gun fight" to describe the city's current feelings of what it has at its disposal to address the rules' goals. Durham hopes that the state will approve a wider array of stormwater management options as being worthy of credits by the state, including some GSI options which currently do not receive credit, such as green roofs (Cox 2012a).

While Durham requests broader options, NC DENR and DWQ will likely want to be cautious in what options they validate as worthy of crediting. The current accounting of credits embodied in the Jordan and Falls Lake Accounting Tools are based largely on the work of Dr. Bill Hunt at NC State (Hunt 2012). The state feels that the current suite of options is credited appropriately and that they have a firm scientific foundation behind them. To obtain further options, Durham will have to cite or provide the data that will convince the state that those options can be added to the available toolbox. Recent evidence suggests that updates can and will happen when the state receives reasonable evidence. Dr. Hunt has recently demonstrated to state officials that permeable pavement can be successfully implemented in the Piedmont region, where the state does not currently provide credit for its use, and the state will be modifying its crediting system accordingly (Gannon 2012a).

If nothing else, Durham can lobby for the regular consideration by the state of new findings and refined data regarding local application of GSI. The city will want the data it collects as part of its GSI pilot programs to have a useful application. If the state can codify a system or schedule whereby new information is incorporated into the accounting tools, this will provide further incentive for Durham to collect such data, or to undertake partnerships with other parties, such as NC State and other local universities, to conduct the necessary research.

8) Continue data collection regarding nutrient loading and GSI performance to provide better targeting of GSI options.

While both the state and Durham are clearly doing the best they can with the data they have, notable knowledge gaps exist which make the choice of how or whether to implement GSI more difficult. These gaps have been noted by the Nutrient Sensitive Waters Science Advisory Board (SAB) which the General Assembly created in the 2010 updates to the Jordan lake rules (N.C. Division of Water Quality 2010). During the February 2012 roundtable with Ellen Gilinsky, Trish D'Arconte detailed several of the areas in which further research was necessary to direct efforts to address the lake rules (D'Arconte 2012). Many of these issues pertained to the specific sources of nitrogen and phosphorus in the watersheds feeding into Jordan and Falls Lake. For instance, when devising the rules NC DENR used general models for sources of nitrogen and phosphorus, particularly highlighting agricultural lands as a primary source of those nutrients. However, little is known about the particular farm lands in Durham County and the precise measures of those nutrients flowing into water ways from each particular parcel (Cummings 2011). Another missing piece of data is the natural atmospheric deposition levels of nitrogen and phosphorus in the Durham area, which would then translate into the amounts present in stormwater as it falls (D'Arconte 2012). Finally, there are noted variations in the flow of stormwater throughout the seasons. As plants become dormant in the winter, less water is evotranspirated and thus there are higher flows into water bodies during these months. This could cause changes in GSI performance that should be incorporated into the models for nutrient mitigation that the state makes available to local jurisdictions.

Fortunately, Durham is well placed to obtain more information on these topics. One of the leading research centers for GSI in the country is located at North Carolina State University, headed by Dr. Bill Hunt. Research into bio-retention options for Ellerbe Creek runoff was performed in 2010 by students at Duke University, and Bill Holman of the Nicholas Institute for Environmental Policy Solutions has been heavily involved in the lake rules processes, demonstrating the potential of Duke as another source of research assistance. The city has also realized the need for it to collect its own data on GSI performance, and in its burgeoning GSI pilot programs it has incorporated data collection efforts to add to the repository of available information on local GSI efficacy (Cox 2012c).

While all areas must do the best they can with the data available, the relative youth of this field should lead to high returns on research investment with much yet to be discovered. The value of this knowledge could extend to other areas facing similar stormwater management needs, and thus the state should also take an interest in the research process and potentially support financially information gathering which could be extended to other localities in the future.

9) Review and update Durham codes that may unknowingly be discouraging or blocking the implementation of GSI.

A potentially overlooked piece of the GSI implementation process relates to the nuts and bolts of city administration, namely the codes and statutes that regulate what infrastructure is built and how. It is very likely that standards exist for construction in multiple areas that are incompatible with the requirements of GSI. Thus, even should the city commit to extensive GSI installation, there are potential regulatory roadblocks in the form of construction requirements that will create construction delays or require additional time for modification of existing statutes.

Marc Cammarrata, the current director of Philadelphia's Department of Watersheds, highlight this obstacle in a presentation at the Cities Alive green roof conference in December 2011. As the city moved to implement GSI, they discovered that specific Philadelphia codes should be modified to allow or encourage GSI. For instance, minimum levels required for parking spaces or street widths increase the amount of impervious area, requiring increased levels of GSI installation to counteract the impervious coverage (Cammarata 2011). Though it has been previously detailed how Philadelphia's example does not fully apply to Durham's situation, the review and modification of city codes is a best practice that Durham could surely undertake. The city could start now with reviewing the code with an eye towards its conflicts with GSI, even if GSI is never adopted on a wide scale. Like the engineering evaluations of roof capacity for green roof installation, a review of codes is a straightforward and relatively inexpensive step in the process that nonetheless is crucial to allowing GSI incorporation.

APPENDIX A: Comparison of Green Stormwater Infrastructure (GSI) to Related Concepts and Terms

As a burgeoning field, green stormwater infrastructure is not a ubiquitous term with common acceptance or recognition by all municipalities or countries. While many areas are investing in sustainable stormwater management, the ways in which they refer to those practices and the categories they include can vary. GSI was used for this case study to clarify the application to stormwater management, since some sources define "green infrastructure" (without stormwater explicitly included) quite broadly in certain contexts, as noted below. The following are related stormwater management concepts that have appeared in the course of research for this project. This appendix provides definitions to illustrate relationships and draw boundaries between GSI and the varying terminology detailed here.

Best Management Practices (BMPs) or Stormwater Control Measures (SCMs): BMP is a common term in the lexicon of stormwater water management, but also one of the broadest. BMPs were originally conceived to describe treatment practices for processing wastewater, and eventually came to encompass stormwater management techniques as well. Since the term itself does not reference stormwater and since the application of the term can refer to different types of water management, stormwater control measure has emerged as an alternative phrase equivalent to stormwater BMPs (National Research Council 2008). The BMP/SCM umbrella can be quite broad and include not just structural elements but general processes and practices as well. The EPA's National Menu of Stormwater BMPs includes public education and engagement actions, as well as steps taken to maintain water quality during and after construction (U.S. EPA 2012b). In contrast, the DWQ's Stormwater BMP Manual focuses on constructed options, and while this set of measures hews closer to a GSI definition, the manual also includes larger elements such as retention ponds and constructed wetlands which tend to fall outside the range of GSI (NC DENR 2007).

Low-Impact Development (LID): LID refers to a general framework of practices for new development that recognizes the impact that new construction has on stormwater flows and which seeks to mitigate those effects. This concept encompasses land management and construction practices, such as maintaining maximum amounts of green space in a project and developing more compact building footprints or preserving riparian buffers (undeveloped land surrounding streams and other water bodies), as well as GSI options (National Research Council 2008). Thus, GSI constitutes a set of options under LID, but are not the only steps that exist under this heading.

Green Infrastructure: Some cities or areas may use "green infrastructure" interchangeably with the concept of "green *stormwater* infrastructure." The EPA in its documentation largely refers to green infrastructure in this manner, though it does make passing references to the "scale of a city or county" (U.S. EPA 2012c). When green infrastructure is thought of at that level, it "refers to an interconnected green space network… that is planned and managed for its natural resource values and for the associated benefits it confers to human populations" (Benedict and McMahon 2006). Those benefits extend beyond stormwater management, and therefore this paper employed GSI to avoid confusion with the more holistic definitions of green infrastructure.

Stormwater Urban Drainage Systems (SUDS) and Natural Drainage Systems (NDS): Though not referenced in this paper, these terms are used by governments in the United Kingdom (SUDS) and in Seattle (NDS) and are roughly equivalent to GSI (Scottish Environmental Protection Agency 2012; Seattle Public Utilities 2011). These additional terms thus further reflect the competing terms and designations which exist in this emerging field.

APPENDIX B: Definitions of Most Common GSI Options

This paper does not have the space to investigate each GSI option individually in terms of its applicability to the conditions present in Durham. However, there is a considerable list of GSI which is either credited by the state of North Carolina in its BMP Manual, or which is in use by other cities and thus has received attention or research within this field. Though not exhaustive, the following is a list of common GSI options with descriptions of their designs and benefits.

Green Roofs: Green roofs are vegetated layers which rest on top of a typical roof's watertight membrane, with plants rooted into a thin growing medium that rests on root barrier and water filtration layers (Green Roofs for Healthy Cities 2012). Distinct from planter boxes or potted plants placed on roofs, green roofs are permanently installed layers which are usually intended to cover the majority of a roof's square footage. Two general classes of green roofs exist. The first is extensive green roofs, which have relatively shallow (four to six inch) layers of growing media that are usually planted with sedums, small, hardy plants that require less irrigation and active maintenance. The second class is intensive green roofs, which incorporate deeper growing media and can support larger plants that make the green roofs appear more like gardens. Green roofs are most commonly installed on surfaces with shallow slopes, but extensive green roofs have been placed on roofs at angles as extreme as 33 degrees (Greenroofs.com 2011). Green roofs can be installed as a series of plant plugs which begin growing after installation, or via pads or rolls of pre-grown green roofing that is produced off-site and transported to the installation location intact. Depending on local weather conditions, drip irrigation systems may be incorporated into the green roof structure to provide water to the plants during dry spells. Some stormwater is absorbed by the green roof and used by the plants or evaporated from the green roof surface, and the flow of the remaining stormwater is slowed and prolonged during rain events.

Permeable Pavement: Permeable pavement options come in three varieties, which are all meant to increase the infiltration of traditional paved surfaces. The first two permeable pavement options are similar, porous asphalt and pervious concrete. In both cases, the usual asphalt or concrete mixture is modified to create sufficient space between the particles to allow some water to filter through the pavement, without sacrificing the load-bearing capacity of the surface (Interlocking Concrete Pavement Institute 2008). The third alternative is permeable interlocking concrete pavement. With this option, contractors modify the design and installation of concrete pavers to preserve space between the pavers for water infiltration, rather than seeking a tight seal. Installers also incorporate particular aggregates to fill the gaps between pavers so that water can easily pass through, and this design avoids infill such as sand that infiltrates water at slower rates (Interlocking Concrete Pavement Institute 2008).

Rain Gardens: A rain garden is a landscaped and planted area specially designed to draw and filter stormwater flows, and can typically infiltrate a volume of water 30% higher than a comparable area of normal lawn (Bannerman and Considine 2003). Construction of the garden involves deliberate siting, shaping, and planting of the garden to direct stormwater to its area and to infiltrate the water at a rate fast enough to avoid flooding.

Since the gardens attract and retain larger amounts of stormwater than typical areas of a lawn they must be installed with careful attention to the characteristics of the site, including proximity of buildings and typical stormwater volumes. Rain gardens typically involve the use of native plantings to enhance aesthetics while maximizing the performance of plants in water absorption (Low Impact Development Center 2007).

Bioswales: Bioswales exhibit some similarities to rain gardens in that they are vegetated open areas designed to receive and filter rainwater, but they differ in certain design characteristics and general usages. They are narrow, long channels which incorporate dense plantings and both infiltrate the water they receive as well as convey it to traditional gray infrastructure systems (Clark and Acomb 2008). Use of bioswales is limited to areas with appropriate slopes for channeling water without significant erosion, thus flat or steep areas will not support this GSI option. They are usually employed in medians on highways or in parking lots or along roadsides.

Stormwater Tree Trench/Filterra: Tree pits and plantings in sidewalks are already a commonplace design practice, but traditional designs do not maximize the filtration capabilities of these plants and supporting soils. Stormwater tree trenches incorporate inlets separate from the larger sewer system to channel stormwater flows along streets and curbs into the trenches before they reach sewer intakes (Philadelphia Water Department 2011b). The trenches then connect multiple tree plantings underneath the pavement and allow water use by the plants above. Excess water that is not used by the plants then flows into gray infrastructure systems via connecting pipes, having been filtered by the growing media in the trench (Philadelphia Water Department 2011b). Filterra is a trademarked version of this system that came up regularly in conversations with Durham Stormwater Services. Product schematics on their website show a similar system to a stormwater tree trench, but isolated to a single tree or shrub rather than a series of connected plantings (Filterra Bioretention Systems 2009).

Cisterns/Rain Barrels: By channeling stormwater flows from roofs into temporary storage, cisterns and rain barrels reduce the first flush of water flowing into gray infrastructure during a rain event. Additionally, they provide water to the owner for other uses, such as irrigation or toilet flushing. Users must pay proper attention to the level of water in the cistern or rain barrel and either use the water or expel it between rain events to maintain storage capacity (Philadelphia Water Department 2011a).

APPENDIX C: Individuals Interviewed for Project Research

Name	**Role and Organization**
Drew Cummings	Assistant County Manager, Durham County
Dan Jewell	Partner; Coulter, Jewell, Thames Landscape Architecture
Michael Goodmon	VP of Real Estate, Capitol Broadcasting
John Warasila	Partner, Alliance Architecture
John Cox	Stormwater Quality, City of Durham Stormwater Services (via email)
Paul Wiebke	Assistant Stormwater Manager, City of Durham Stormwater Services
Sandra Wilbur	Project Manager, City of Durham Stormwater Services
Jennifer Buzun	Engineer, City of Durham Stormwater Services
Helen Youngblood	Senior Planner, Durham City-County Planning Department
Sarah Young	Planner, Durham City-County Planning Department
Thomas Dawson	Planner, Durham City-County Planning Department
Rich Gannon	Environmental Supervisor, NC Department of Environment and Natural Resources (by phone)
Bill Hunt	Associate Professor, NC State University Department of Biological and Agricultural Engineering
Bill Holman	Director of State Policy, Nicholas Institute for Environmental Policy Solutions
Nora Barger	Energy Efficiency Coordinator; Clean Energy Solutions, Inc.
Peter Raabe	North Carolina Conservation Director, American Rivers
Mike Dupree	Durham Soil and Water Conservation District
Clayton Rugh	Manager and Technical Director, Xero Flor
Chris Dreps	Executive Director, Ellerbe Creek Watershed Association
Tim Pennigar	Facilities Manager, Duke University Health System

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