ANALYZING POTENTIAL BENEFITS OF GREEN ROOFS IN FUTURE GROWTH SCENARIOS IN NEW HANOVER COUNTY

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ABSTRACT:

Green roofs are gaining popularity in different parts of the world. This paper examines green roofs as a stormwater runoff management best management practice (BMP). Future growth scenarios, provided by New Hanover County's long-term plan are likely to include a large increase in impervious surfaces. With the county being relatively small and already heavily developed, open space is at a premium. Traditional BMPs such as retention ponds require a large geographic footprint which is expensive, reduces buildable area, and requires significant land-disturbing activities which increases the risk for negative environmental impacts. The analysis was done by taking 2010 census data that included population, housing units, and jobs, and extrapolating these variables for three separate growth scenarios. The results were entered in the Environmental Protection Agency (EPA) Impervious Surface Growth Model to estimate the amount of impervious surface associated with each growth scenario. Rainfall volumes on the future impervious surface areas were calculated for a typical 30 minute, 1.5 inch rainfall event (a 1-year frequency storm for the area). Three different retention capacities were used in the analysis based on previous published studies. The analysis found that stormwater runoff volumes captured by green roofs could potentially have a significant impact on future stormwater planning for new development by replacing or reducing the footprint of traditional BMPs, saving money and space.

BIOGRAPHY

Ian Flannery was born and raised in Central Maine. He enlisted in the Army after high school as a Cavalry Scout and served four years with the 82nd Airborne Division including a 15-month combat tour in Iraq. After being honorably discharged in 2009, Ian went to the University of North Carolina Wilmington where he earned a Bachelor of Science in Environmental Science with a concentration in Biology in 2012. Ian has also earned a Master Certificate in Geographic Information Systems from NCSU while pursuing the Master of Environmental Assessment degree.

Since graduating from UNCW, Ian has been working in the environmental field, transitioning from hazardous waste and materials management to an environmental compliance management position for a national homebuilder and developer. Ian is a Certified Professional in Erosion and Sediment Control (CPESC), Certified Erosion, Sediment, and Stormwater Inspector (CESSWI), and a Certified Inspector of Stormwater and Erosion Control (CISEC). He currently lives in Wilmington, NC with his wife, Hannah.

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ABBREVIATIONS AND ACRONYMS

AC	ACRE(S)
BMP	BEST MANAGEMENT PRACTICE
CBG	CENSUS BLOCK GROUP
CFS	CUBIC FEET PER SECOND
CM	CENTIMETER
CSS	COMBINED SEWER SYSTEM
CWA	CLEAN WATER ACT
EPA	ENVIRONMENTAL PROTECTION AGENCY
FT^2	SQUARE FOOT/FEET
GAL	GALLON
ILM	WILMINGTON INTERNATIONAL AIRPORT
ISGM	IMPERVIOUS SURFACE GROWTH MODEL
LID	LOW-IMPACT DEVELOPMENT
M^2	SQUARE METER(S)
MDC	MINIMUM DESIGN CRITERIA
MM	MILLIMETER
MS4	MUNICIPAL SEPARATE STORM SEWER SYSTEM
NCDEQ	NORTH CAROLINA DEPARTMENT OF ENVIRONMENTAL QUALITY
NGO	NON-GOVERNMENTAL AGENCY
NHC	NEW HANOVER COUNTY
NPDES	NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM
USGS	UNITED STATES GEOLOGICAL SURVEY

INTRODUCTION:

Stormwater runoff is an increasingly important factor when it comes to pollutants in U.S. waters. In an undeveloped environment, stormwater runoff is naturally mitigated and reduced in a number of different ways. First, the precipitation hits tree canopy or ground vegetation which reduces the impact and soil erosion. Depending on soil types and their corresponding saturation capacities, water will begin infiltrating into the ground immediately[1]. As a precipitation event continues, enough water volume may fall so that the water begins to pool and move horizontally across the ground surface. The ground vegetation plays an important role at this time. The plants and their roots hold the soil in place preventing or slowing down particle transport. The vegetation will capture any sediment or other pollutants that may have become dislodged, preventing them from traveling further downstream. Most importantly, the stems and shoots of the plants slow the velocity of the runoff and give it time to infiltrate into the soil instead of concentrating and forming larger flows[2]. Developed environments have impervious surfaces that have been introduced by humans. Impervious surfaces are those in which water will not readily infiltrate enough to reduce volume or velocity of flow. The more impervious surface that is introduced, the greater amount of runoff there will be. Along with increased volume, the environment loses its ability to naturally treat the pollutants in the stormwater[1]. There are many pollutants found in developed environments that can be picked up and transported. Contaminants of concern include oils, grease, and sewage. Fertilizers and pesticides along with organic materials, such as pet waste and yard debris, are common in and around many American homes and these chemicals are frequently introduced into local surface waters when it rains[3]. Other common household pollutants include soaps and detergents used in the cleaning of vehicles, driveways, and buildings[4]. Even heat could be considered a pollutant. In cold-water streams for example, heat is considered a pollutant because of its effects on organisms that cannot survive in elevated temperatures[5]. Developed areas tend to contribute heat in the form of stormwater runoff, because of the heating that occurs as the water travels across dark surfaces such as rooftops and asphalt[6].

Regulations

Water quality regulations started to develop in 1972 with the passage of the Clean Water Act (CWA). The CWA was passed in response to a few highly publicized environmental disasters that started an environmentalist movement demanding greater protections. The CWA aimed to regulate point source discharges into waters of the U.S. The so-called “teeth” of the CWA is the National Pollutant Discharge Elimination System (NPDES). The NPDES is the permitting and enforcement section of the CWA. Within the NPDES there are 12 different program areas, each one regulating a different type of discharge into waters of the U.S. One of these program areas regulates discharges of stormwater and classifies stormwater discharges for five major sources: Construction activities, industrial activities, municipal sources, transportation sources, and oil and gas[7].

A major component of NPDES stormwater permitting is the requirement to have engineered plans that dictate how the stormwater falling on that particular site will be managed. For example, an engineer designing a neighborhood would be required to seek a general permit for stormwater discharges from construction activities. For the plans to be approved and the permit issued, the engineer must show that both water *quality* and *quantity* will be managed in accordance with requirements. The requirements may differ from state to state and even between municipalities. In North Carolina, plans are required to show how the first inch of rain in non-coastal areas and first 1.5 inches of rain in coastal areas will be captured, treated for possible pollutants, and discharged[8]. The engineer has to take into account a multitude of factors such as historical rainfall data, topography, geology, soil types, and hydrology.

In order to properly satisfy the requirements of the permits, engineers and planners have a diverse toolbox of best management practices (BMPs). BMPs are classified as stormwater control, erosion control, or sediment control. Often these BMPs are temporary and function to treat the stormwater that falls on a site while it is under construction (i.e. in development). As part of the construction sequence, permanent BMPs are built that will continue to treat stormwater after construction ends. Sometimes temporary construction BMPs are converted into permanent BMPs at a pre-determined time in the sequence of construction. Depending on the geographic location and local jurisdiction, the specific design requirements of these BMPs vary, but the same basic principles apply across the U.S. BMPs must capture peak flows of water by conveying it to a storage area, give it settling time to allow pollutants to fall out of suspension, and then release what should be clean water in a controlled matter off site, where it will eventually infiltrate into the ground and/or enter existing surface waters. The controlled manner of release is intended to decrease the chances of downstream flooding by controlling the discharge into the surface waters.

Traditional stormwater management consists of a conveyance system that brings the stormwater runoff to a collection system. A basic example of this would be a residential neighborhood with curb inlets. The runoff that comes from the houses, driveways, and street is directed to the inlets. The inlets route the water into a network of pipes that will eventually discharge into a retention pond. The pond could have one of several different methods of slowly drawing down and discharging the water. The general purpose of the controlled drawdown is to give the pollutants carried with the stormwater time to settle out of suspension before it is released into a receiving waterbody. Municipalities meeting certain size criteria are required by the EPA to manage the network of stormwater conveyance and collection systems, known either as municipal separate storm sewer systems (MS4) or combined sewer systems (CSS). Within an MS4, stormwater is *separated* from sewer waste. The sewage goes to a treatment plant whereas the stormwater is discharged into surface waters with no additional treatment. Combined sewer systems route stormwater to the same treatment plants as the sewer waste. Large rains can overwhelm these systems and cause discharges of sewage into nearby surface waters.

A significant disadvantage of traditional BMPs are the spatial and financial constraints it puts on the engineer or plan designer. As a planned drainage area grows, so too does the need for larger and more complex stormwater management systems. These systems can be costly, due to the nature of the work that is required to install them. Large, heavy concrete pipes have to be laid with a specific attention to detail to elevation to ensure positive drainage. This requires heavy equipment and surveying crews. The retention system then has to be planned in an area conducive to direct the stormwater to it, generally on side of the site with the lowest elevation. More heavy equipment is needed and the dirt or "spoils" must be taken somewhere if it cannot be used on site. Traditional retention systems such as ponds inherently take up a large area of the site. In more developed areas where open space is limited, this area could otherwise be used for additional buildings, parking, recreation areas, or other functions that could bring additional value to the property. Engineers must design the system and implement BMPs in the way that will most effectively use the planned space while still meeting the requirements of the stormwater system. A conveyance system that consists of concrete pipes does nothing to treat the water quality until it reaches the retention area. Any pollutants are expected to be treated at the last BMP of the system, before being released off-site. This could have negative consequences for the water quality of the receiving waterbody.

Climate

Stormwater sewer systems across the United States, especially in more established cities, have been built and added on to over the years. Many of these systems were installed before the passage of the Clean Water Act and the regulation of stormwater. Recent extreme precipitation events have shown how vulnerable the aging stormwater infrastructure can be. An example is the series of storms that hit the southeastern United States in October 2015. Many areas of South Carolina received precipitation amounts over three days that classified it as a 1,000-year storm event, meaning the likelihood of a storm of that magnitude occurring in any given year is 1 in 1,000. Around the area of Columbia, in the central part of the state, several dams and canals partially or completely failed leading to widespread, catastrophic flooding. The storm caused fatalities and resulted in an estimated 1 billion dollars in damage and other associated costs[9]. It may not be practical to design all stormwater systems to handle precipitation amounts of this magnitude, but it illustrates the fact that intense rain events are becoming more frequent. Figure 1 shows the increase in percentages of heavy storm events (defined in that study as a 5-year storm) for each decade of the 20th century.

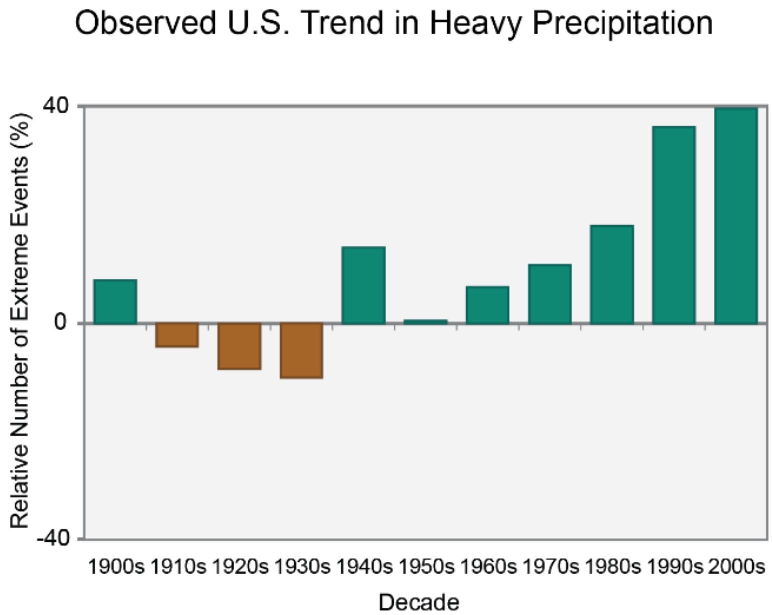

FIGURE 1: Graph from 2014 U.S. Global Change Research Program 2014 Climate Assessment[10]. Adapted from Kunkel et al. 2013[11]

The United States Census Bureau estimates that the population in the United States will reach 417 million by the year 2060[12]. This type of population growth is expected to drive development and, as a result, a large increase in the amount of impervious surface in developing areas. Impervious surface area varies depending on geographic location (for example, urban vs. suburban vs. rural). A 2012 study using satellite imagery to estimate impervious surface coverage in the contiguous U.S. found there was 2.4% impervious surface area[13]. A separate study estimated that by the year 2100, the percent impervious surface in the United States could increase by as much as 164% compared to the levels modeled in 2000[14]. To compound the problem, most man-made impervious surfaces are replacing surfaces that would normally have contributed to infiltration of stormwater. In an environment with increasing impervious surface, not only is the amount of stormwater runoff increasing, but the natural areas for mitigating it are decreasing.

The population of the U.S. continues to grow every year, but the nation's water supply is a finite resource. Fresh surface waters, such as lakes, rivers and streams, account for less than 0.25% of the total water on Earth[15]. In 2010, the U.S. withdrew 306,000 gallons of freshwater a day from surface and groundwater sources, with the main uses being for thermoelectric power generation and irrigation[16]. The U.S. surface waters also provide water for drinking and bathing for the population.

The growth in population and corresponding increase in impervious surface in the United States is a problem in itself, however, there is another issue serving as a multiplying factor: climate change. As Earth's temperatures increase, so does the amount of evaporation and resulting atmospheric water vapor. Although there is debate on how exactly this will effect precipitation patterns at local scales, it is likely that most areas currently in wet climates will receive increasing and intensifying precipitation with global warming[17, 18, 19, 20]. This process is commonly known as “wet gets wetter, dry gets dryer,” meaning areas that are currently dry or arid, could receive less precipitation as the atmosphere warms.

As population continues to grow and traditional BMPs become more costly, it is driving the design and implementation of “green” or low-impact development (LID) BMPs. In general, the objective of green stormwater BMPs is to capture and/or treat stormwater at its source, instead of routing it to conveyance systems where it is concentrated and usually ends up in surface waters. One of the green BMPs that is becoming increasingly popular is green roofs.

History of Green Roofs

Incorporation of vegetation in architecture has been practiced by mankind for centuries. One of the more famous early examples was the Hanging Gardens of Babylon which were constructed around 500 B.C.[21] Cultures around the world continued to use the practice, mainly as an insulation technique to keep living areas protected from temperature extremes. In more modern times, green roofs were seen as more of an aesthetic or novelty feature. In the 1960’s, rising oil prices encouraged more research into using these roofs as a way to save energy, especially in Europe. In Germany in the 1980’s, green roofs were increasing by 15-20% annually and by 1989 there were over 1 million square meters installed in the country[22]. By the 2000s, research was being done on the various benefits of green roofs. Some of these included: stormwater quality, stormwater retention, wildlife habitat, reduction of urban heat islands, air quality, and increased thermal insulation[22, 23, 24]. An additional benefit that would be less predictable than others is that green roofs can last longer than a traditional roof, as they have been shown to extend the life of existing roofs after retrofitting[24, 25, 26].

FIGURE 2: Artist’s depiction of the “green roofs” in Babylon. Image from history.com[27].

Green Roof Construction

A variety or materials and methods are used to construct green roofs. These are largely based on the geographic location of the site as well as the physical characteristics of the roof itself. If these roofs are being constructed on pre-existing buildings, the responsible parties have to ensure that the structure can support the weight of a green roof system. This may involve having engineers evaluate load-bearing standards and, if necessary, providing reinforcement for the roof to handle the additional weight.

A green roof typically consists of three parts: An underlying waterproof membrane, a growing media (soil or substrate), and vegetation. The vegetation and medium will vary greatly depending on geography and climate. A green roof whose vegetation is set up to be mainly self-sustaining is considered an extensive roof, while green roofs that will require more maintenance and upkeep to the vegetation and other components are called intensive roofs. Green roofs use multiple natural processes to manage stormwater that include: Infiltration, detention (the capture and slow release of water), retention (the capture and removal of water before runoff), evaporation, and transpiration. Vegetation and its growing media should be selected based on its tolerance for the specific area and its capacity for the previously mentioned processes. Several studies on the influences of different media and vegetation on stormwater runoff reduction have been conducted (Table 1) showing results in runoff retention capacities of varying soil types, vegetation, and rainfall intensities. With all of the variables included, these studies show that there is a significant increase in the amount of runoff reduction just by adding a layer of growing media. Further reduction is obtained by adding vegetation of varying species and densities.

TABLE 1: Graph summarizing recent studies on effects of media and vegetation on roof runoff compared to control (conventional roof with expected ~100% runoff or ~0% retention).

Study	**Roof Surface (Depth & Material)**	**Average Retention %**
VanWoert et al. 2005[28]	Gravel Ballast (2cm)	27.2
	Growing Media (2.5cm)	50.4
	Media + Vegetation	60.6
Bliss et al. 2008[29]	Control	N/A
Natural Storms	Growing Media (14cm) and Vegetation	78.8
Controlled Storms	Growing Media (14cm) and Vegetation	50.4
Nardini et al. 2012[30]	Bare Rooftop (Control)	0
	120mm Growing Media	63.3
	120mm Growing Media and Herbaceous Vegetation	90.5
	200mm Growing Media	83.3
	200mm Growing Media and Shrub Vegetation	90.5
Harper et. al 2015[31]	Control	0
	Growing Media	40
	Growing Media and Vegetation	60
Buccola and Spolek 2011[32]	Control	N/A
Heavy Intensity Storm	5cm Growing Media and Vegetation	20
Heavy Intensity Storm	14 cm Growing Media and Vegetation	56
Medium Intensity Storm	5cm Growing Media and Vegetation	36
Medium Intensity Storm	14 cm Growing Media and Vegetation	64

Growing Media & Vegetation

It has been shown that the growing media may be more important than the vegetation for the purposes of stormwater retention[32]. Results showing greater retention from control roofs containing just substrate and no vegetation could be an indicator that vegetation coverage affects evaporation from the media, which limits its retention capacity for subsequent precipitation events[33]. Though vegetation is not as consequential for overall runoff retention, there are other areas where it may be more important such as water quality, as vegetation is able to filter various pollutants commonly associated with stormwater[28, 29, 30, 31]. Other research has shown how vegetation helps to mitigate the effects of urban heat islands[34, 35, 36].

Cost-Benefit Case Studies

Various case studies have been completed that study the effects of public and, in some cases, private incentives offered to private home or business owners. The objectives of these studies were to determine, from a cost-effectiveness perspective, the feasibility of offering tax credits, stormwater fee reductions, or similar monetary incentive. An ideal cost-effective incentive program would result in the municipality spending less on incentives for the green-roofs than it would otherwise have to spend on the costs associated with the additional stormwater infrastructure without green roofs. The demand for labor and materials in one of these programs would likely include ancillary benefits to the local or regional economy-plus the environmental benefits that cannot be as easily quantified.

One such case study was performed in 2008 for the City of Portland, OR[37]. This study calculated that a 40,000 square foot (ft^2) green roof placed in Portland would reduce stormwater from 877,000 to 406,000 gallons annually, compared with a conventional roof, a reduction of 56%. Peak flow would be reduced from 0.85 cubic feet per second (cfs) to .03, representing a 96% reduction. Based on the 56% reduction rate and a previously estimated one-time stormwater cost of $2.71/$ft^2$ impervious area (i.e. a conventional roof) this study hypothesized that a green roof of the same size would save the city $60,700[38]. The City of Portland now offers incentives in the form of stormwater fee reductions up to 35% for the use of stormwater BMPs such as green roofs, which would expect to yield a continued annual cost savings to the city and private property owners. The city offers reimbursements of $5/$ft^2$ of green roof. As of January 2013 there were more than 172 green roofs and the goal was to establish another 43 acres worth. This would be expected to reduce stormwater runoff by 552,600 gallons per acre[39].

Carter and Keeler (2008) prepared a cost-benefit analysis of replacing all conventional roofs with green roofs in an “ultra-urban” environment in Athens, GA, to offset the need for traditional BMPs common to that environment, such as bio-retention areas, porous pavement, and sand filters. Using both conservative and average estimates, the study compared the overall costs and benefits of a green roof with a 40-year life expectancy and retrofitting traditional roofs with a life expectancy of 20 years. Conservatively, the study found that the green roofs saved \$9.06/square meter (m^2) and \$0.04/m^2 in social and private costs, respectively. This does not include other factors that were considered, such as the beneficial effects on energy and air quality. With just a 4% discount in stormwater utility credit, savings from a 929m^2 green roof would offset the total cost of building the roof by \$9,634.38 over 40 years based solely on the stormwater retention effects. Using average costs provided by private green-roof installers, the study found that the same roof would provide \$19,040.24 in the same 40-year life period to the owner. It should also be noted that the same study found social benefits of replacing the entire watershed with green roofs ranging from \$3,283,488.37 (conservative) to \$5,077,495.58 (average) [40]. This is an annual savings of between \$82,087.21 and \$126,937.39.

The city of Chicago, IL implements a credit of \$0.05/ft^2 of green roof for building permits and also will expedite the permitting process when approved green roofs are planned[41]. In 2006, the city passed a Green Roof Improvement Fund that matches grants at 50% for retrofitting traditional roofs in the city with green roofs up to \$100,000 in certain districts. There are also smaller \$5,000 grants available for smaller residential and commercial projects[42]. As of April 2014, the green roofs within Chicago had the capacity to capture 70 million gallons of stormwater that would otherwise go into the city's combined stormwater sewer system[43].

Nashville, TN (Davidson County) implements stormwater user fees to private businesses and homeowners that can be offset by implementing green BMPs. One specific incentive for green roofs gives rebates (up to \$10/ft^2) for any green roof installed within the city's combined sewer system[44]. A study was done for the city in 2009 as part of developing their "Green Infrastructure Master Plan." The study found that if all 2,132 buildings totaling roughly 20.7 million ft^2 within the city's CSS were to be retrofitted to green roofs, it would remove 343 million gallons from the CSS every year[45]. Figure 3 is from the Master Plan and illustrates the potential green roof sites in the CSS.

Philadelphia, PA plans to invest \$2.4 billion over the next 25 years in infrastructure, including funding grants to property owners and developers to encourage retrofitting conventional properties with LID practices such as green roofs [46]. Grants are issued (up to \$100,000) to property owners who submit qualifying designs and execute the approved plans[46]. The grants are based on acreage of impervious surfaces and the practices must manage at least the first inch of runoff[46].

Onondaga County, NY includes the city of Syracuse. The county government has implemented a tiered grant program that offers funding for new construction or retrofitting of stormwater practices that meet the LID standards. The county identified certain areas of their combined sewer system that are higher priority and projects in these areas are eligible for more funding than other areas. Since Onondaga County implemented the program, it has provided $10 million in funding to 88 projects. The result is 43 million gallons of stormwater captured[47].

In Washington, D.C., the district's Department of Energy and Environment initiated a green roof rebate program that can pay back between $10 and $15/ft^2 in watersheds that have been designated as high priority[48]. There is no defined maximum project size to receive the benefits, so the potential for property owners' savings is relatively large, especially for commercial entities who build multiple properties. For smaller buildings (less than 2500 ft^2), prospective green roof customers can receive funding towards a structural assessment[48].

Figure 3: Potential green roof locations in the Nashville/Davidson Co. combined sewer system district[45].

New Hanover County, North Carolina

Located in southeastern North Carolina, New Hanover County (NHC) was home to approximately 216,000 people as of 2016. The county covers 144,000 acres. 126,000 of those acres are dry land[49]. The annual recorded rainfall at Wilmington International Airport (ILM) was 70.9 inches in 2016[50]. The 1.7 people per acre is relatively high compared to its neighbors Pender and Brunswick Counties. These two counties have a population/acre of 0.2 and 0.1, respectively[51, 52]. NHC has experienced steady growth over the past several decades and it is expected to continue. In 2016, in response to the rapid growth, county officials published "New Hanover County Comprehensive Plan 2016." The 25-year planning strategy identifies and attempts to strategize solutions for an expected growth of another 123,000 residents by the year 2040, an increase of 57%. With this population growth comes the need for infrastructure, industry, and homes for these residents. As of 2016 NHC had 45,000 acres of undeveloped land. 16,000 of these acres are protected by various local, state, and federal agencies and non-governmental organizations (NGOs). Figure 4 is a 2016 land-use map included in the Comprehensive Plan.

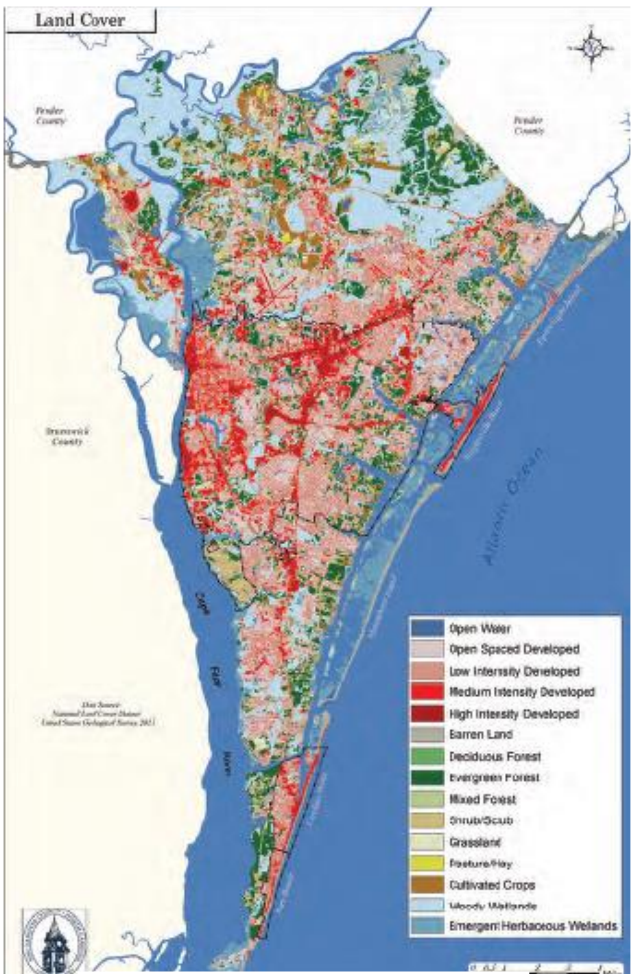

Figure 4: 2016 NHC Land Cover map.

NHC can expect a significant increase in impervious surface associated with its estimated population growth. Additional impervious surface will contribute to greater volumes of stormwater runoff being directed to the area's surface waters. Engineers and planners will continue to design traditional stormwater BMPs as required by regulations in the most cost effective manner possible however, implementing LID and green BMPs like green roofs could potentially provide financial and environmental benefits.

The North Carolina Department of Environmental Quality (NCDEQ) has been recalculating and designing their stormwater management BMPs, detailing the construction and design of each with what they call Minimum Design Criteria (MDC). Under the MDC models, BMPs are separated into Primary or Secondary BMPs. Primary BMPs would be those that, "Can stand alone when designed per the MDC to treat the design storm depth."[53] Green roofs cannot always be considered primary because they may not meet the criteria for water *quality* treatment. From a water *quantity* standpoint, the new regulations consider green roofs to treat 100% of annual stormwater runoff if designed per the MDC[53]. Water quality goals could potentially be met by directing any effluent from the green roof to storage tanks such as rain barrels or cisterns, or the runoff could be routed through an additional BMP designed to meet water quality standards.

OBJECTIVE STATEMENT:

This paper will analyze how introducing green roofs in future development in NHC can mitigate the area needed for traditional BMPs thus increasing usable acreage while also reducing costs of stormwater infrastructure. If found to be a significant impact the data can be used to incorporate green-roofs into regulatory requirements or an incentive system beneficial to the landowners and the environment.

METHODS:

Four separate growth scenarios formed the basis of the analysis. Low and high growth estimates were provided in the NHC Comprehensive Plan[49]. A "medium" growth scenario was estimated by averaging the low and high. A fourth scenario, "zero growth," was included as a control. The EPA Impervious Surface Growth Model (ISGM) was used to estimate the increase in impervious surfaces based on three user inputs: "Census Block Group," "Jobs Added," and "Housing Units Added." The ISGM only recognizes certain pre-programmed census block groups (CBGs). Of the 120 CBGs in NHC, only 30 were recognized by the ISGM. Job data was found using 2010-census data[55]. A base for jobs/population was found by dividing the jobs (81,712) by the NHC 2010 census population of 202,667[55]. Housing unit data were taken from the same 2010-census data. These were divided by the 2010 population. Impervious surface data for NHC was found using the National Landcover Dataset in ArcMap (GIS).

To get a representative number with only ¼ of the required data available, average job and housing unit growth was averaged and then divided by 120. These results were then put into the ISGM for each growth scenario. For each growth scenario, the added impervious surface per CBG was averaged and then multiplied by 120 to get a county-wide estimate. Tables 2 shows a summary of the data and calculations used.

TABLE 2: Data used for estimating the job and housing unit growth based on the four growth scenarios. The highlighted columns represent the data entered into the ISGM.

GROWTH SCENARIO	ADDED POP.	POP. TOTAL	ADDED POP. PER CBG	JOBS ADDED	JOBS TOTAL	ADDED JOBS PER CBG	ADDED HOUSING UNITS	TOTAL HOUSING UNITS	ADDED HOUSING UNITS PER CBG
N/A	N/A	ADDED POP. + 202,667	ADDED POP./120	ADDED POP. X 0.403	JOBS ADDED + 81712	ADDED JOBS/120	ADDED POP. X 1.998	ADDED HOUSING UNITS + 101,434	ADDED HOUSING UNITS/120
None	-	202,667	-	-	81,712	-	-	101,436	-
Low	46,359	249,026	386	18,683	100,395	156	23,203	124,639	193
Med	90,373	293,040	753	36,420	118,132	304	45,232	146,668	377
High	134,387	337,054	1,120	54,158	135,870	451	67,261	168,697	561

81,712 Jobs/202,667 Pop. = .403 202,667 Pop./101,436 Hu. = 1.998

Green-roof stormwater retention rates vary greatly as described previously depending on construction, geography, and storm intensity amongst other factors. The studies examined in Table 1 have retention rates ranging from 27.2% to 90.5%. The EPA found that most roofs retained 50% in a 2009 study[57]. Because of the variability, it was decided that this analysis would use the low and high retention rates from the Table 1 comparison, as well as the 50% retention rate established by the EPA. Stormwater volume was based on a 1.5 inch rain event which is roughly a 1 year, 30-minute point precipitation frequency for NHC[58]. Total rainfall volumes were found using the U.S. Geological Survey Rainfall Calculator[59]. Acreage had to be converted into square miles for the calculator. Units were converted back into acres for the results. The rainfall volumes are based on a 40,731 gal/ac. rate for a 1.5 in. rain event.

RESULTS

Using the inputs from Table 2, the total impervious was found for each growth scenario (Table 3) by entering the data into the ISGM.

TABLE 3: Added impervious surface results for the four growth scenarios

GROWTH SCENARIO	AVG. IMPERVIOUS ADDED PER CBG (Ac.)	ADDED IMPERVIOUS (Ac.):	TOTAL IMPERVIOUS AFTER NEW DEVELOPMENT (Ac.):
	From EPA ISGM (AVG. of the 30)	AVG. IMPERVIOUS ADDED PER CBG X 120	ADDED IMPERVIOUS + 41,648
None	-	-	**41,648**
Low	19.36	2,323.2	**43,971**
Med	35.87	4,304.4	**45,952**
High	50.99	6,118.8	**47,767**

Using the impervious surface data from Table 3, the rainfall volumes for the storm event was established by entering the data in the USGS Rainfall Calculator (Table 4). Tables 5, 6, and 7 display the volumes of stormwater that would be captured by green roofs depending on the growth scenario. The three graphs are categorized according to the retention capacities of the green roofs. These analyses were done only on the future impervious surfaces. They do not include the existing (from 2010 data) impervious surfaces however one analysis was done to estimate savings by retrofitting the existing impervious surfaces (Table 8).

TABLE 4: Data from Table 3 was used as the base for added impervious for the three growth scenarios. The volume shown in gallons is the total volume of stormwater that will fall on the green roofs in that scenario during a 1.5 in. rain event.

Impervious Surface Replaced by Green Roofs (Ac.)

Green Roof Coverage:	*Green Roof Coverage (Ac.) with **10%** Replacement of Added Impervious*	*Stormwater Volume (gal.) hitting green roofs with 1.5" event*	*Green Roof Coverage (Ac.) with **25%** Replacement of Added Impervious*	*Stormwater Volume (gal.) hitting green roofs with 1.5" event*	*Green Roof Coverage (Ac.) with **50%** Replacement of Added Impervious (Ac.)*	*Stormwater Volume (gal.) hitting green roofs with 1.5" event*
Low Pop. Growth	232	9,384,422	581	23,721,734	1,162	46,922,112
Medium Pop. Growth	430	17,465,453	1,076	44,315,328	2,152	88,630,656
High Pop. Growth	612	25,025,126	1,530	62,562,816	3,059	125,125,632

TABLE 5: Using the volume data from Table 4, the volume of captured runoff was calculated using a 27.2% retention rate during a 1.5 in. rain event.

Stormwater Runoff Captured (Gal.) with 27.2% Retention

Green Roof Coverage:	*Total Stormwater Volume (Gal.) falling on Green Roofs with **10%** Replacement of Added Impervious*	*Runoff (Gal.) Captured by Green Roof*	*Total Stormwater Volume (Gal.) falling on Green Roofs with **25%** Replacement of Added Impervious*	*Runoff (Gal.) Captured by Green Roof*	*Total Stormwater Volume (Gal.) falling on Green Roofs with **50%** Replacement of Added Impervious*	*Runoff (Gal.) Captured by Green Roof*
Low Pop. Growth	9,384,422	2,552,563	23,721,734	6,452,312	46,922,112	12,762,814
Medium Pop. Growth	17,465,453	4,750,603	44,315,328	12,053,769	88,630,656	24,107,538
High Pop. Growth	25,025,126	6,806,834	62,562,816	17,017,086	125,125,632	34,034,172

TABLE 6: Using the volume data from Table 4, the volume of captured runoff was calculated using a 50.0% retention rate during a 1.5 in. rain event.

Stormwater Runoff Captured (Gal.) with 50.0% Retention

Green Roof Coverage:	*Total Stormwater Volume (Gal.) falling on Green Roofs with **10%** Replacement of Added Impervious*	*Runoff (Gal.) Captured by Green Roof*	*Total Stormwater Volume (Gal.) falling on Green Roofs with **25%** Replacement of Added Impervious*	*Runoff (Gal.) Captured by Green Roof*	*Total Stormwater Volume (Gal.) falling on Green Roofs with **50%** Replacement of Added Impervious*	*Runoff (Gal.) Captured by Green Roof*
Low Pop. Growth	9,384,422	4,692,211	23,721,734	11,860,867	46,922,112	23,461,056
Medium Pop. Growth	17,465,453	8,732,727	44,315,328	22,157,664	88,630,656	44,315,328
High Pop. Growth	25,025,126	12,512,563	62,562,816	31,281,408	125,125,632	62,562,816

TABLE 7: Using the volume data from Table 4, the volume of captured runoff was calculated using a 90.5% retention rate during a 1.5 in. rain event.

Stormwater Runoff Captured (Gal.) with 90.5% Retention

Green Roof Coverage:	*Total Stormwater Volume (Gal.) falling on Green Roofs with **10%** Replacement of Added Impervious*	*Runoff (Gal.) Captured by Green Roof*	*Total Stormwater Volume (Gal.) falling on Green Roofs with **25%** Replacement of Added Impervious*	*Runoff (Gal.) Captured by Green Roof*	*Total Stormwater Volume (Gal.) falling on Green Roofs with **50%** Replacement of Added Impervious*	*Runoff (Gal.) Captured by Green Roof*
Low Pop. Growth	9,384,422	8,492,902	23,721,734	21,468,169	46,922,112	42,464,511
Medium Pop. Growth	17,465,453	15,806,235	44,315,328	40,105,372	88,630,656	80,210,744
High Pop. Growth	25,025,126	22,647,739	62,562,816	56,619,348	125,125,632	113,238,697

TABLE 8: Volumes of stormwater that could potentially be captured during a 1.5 in. rain event by retrofitting existing (2010) impervious surface within NHC.

Retrofitting Existing (2010) Impervious Surface

Green Roof Overall Coverage:	*10%*	*25%*	*50%*
Impervious Removed (Ac.)	4,165	10,412	20,824
Stormwater Volume Falling on Green Roofs (Gal.)	169,440,960	417,085,440	860,238,720
Runoff Eliminated with 27.2% Retention (Gal.)	46,087,941	113,447,240	233,984,932
Runoff Eliminated with 58.9% Retention (Gal.)	99,800,725	245,663,324	506,680,606
Runoff Eliminated with 90.5% Retention (Gal.)	153,344,069	377,462,323	778,516,042

Table 4 illustrates the volume of stormwater that would fall on future green roofs for each respective growth and percent-retention scenario. In the most conservative values in this analysis (Table 5), estimated stormwater retention high population growth scenario in which 10% of the future impervious surfaces are replaced with green roofs having a 27.2% retention rate. Over 6.8 million gallons of stormwater would be captured by the green roofs during a 30 minute, 1.5 in. rain event, effectively preventing it from entering the MS4 and/or public waters. To put that volume into perspective, this would be more than enough water to fill 10 Olympic-sized swimming pools[57]. In 2016 there were four recorded rain events at ILM that met the 1 year, 30 minute design storm criteria[50]. If green roofs were implemented as described in this scenario it would equate to *at least* 27.2 million gallons of stormwater captured during the course of a year. This volume is volume that can be subtracted from the required design volume of traditional BMPs, if there are any, on site.

To highlight a "middle of the road" scenario, the EPA's 50% retention rate (Table 6) can be used in the medium growth scenario where 25% of the future impervious is replaced by green roofs. Under these circumstances, an estimated 40.1 million gallons of stormwater runoff would be eliminated.

A "best case scenario" can be formed by using the results in Table 7. Future development in NHC would consist of 50% of the impervious surface being replaced with green roofs that had a 90.5% capture rate as seen in Nardini et al. (2012). The greatest volume of stormwater captured would be seen in a high growth scenario. 113.2 million gallons of stormwater would be captured and prevented from having to be managed by the county's drainage system.

Table 8 represents the results found by calculating stormwater volume reduction by retrofitting existing (as of 2010) impervious surface in NHC. Using the 2010 impervious surface estimation of 41,648 acres, one 1.5 in. rain event would drop approximately 1.68 billion gallons on the impervious surface present at the time in New Hanover County. The retrofit analysis was done using the 10%, 25%, and 50% as the previous analyses. The results show that just a 10% retrofit of the 2010 impervious surfaces with green roofs with a 27.2% capture rate would capture 46 million gallons. Considering that in 2010 there were at least 4, 30 minute – 1.5" rain events[60], this would equate to over 184 million gallons of stormwater captured over the course of that year.

DATA LIMITATIONS AND FURTHER RESEARCH:

This analysis was done using several variables. Some of these variables, such as the population growth scenario and retention rates, were based on previous studies and statistics. Others however were determined somewhat arbitrarily. An example of this is the green roof coverage rate. It is difficult to determine what a feasible guideline would be for implementing mandatory green roof requirements, however the numbers were selected based on their likely feasibility. Further research could determine if there is an ideal percentage for green roof coverage in new development, possibly a curve at which stormwater management benefits begin to level out at a certain percentage.

Impervious surface estimations were done based on the 2010 data available. All future estimations were based on that data and the population growth scenarios. The analysis assumes that all factors would remain as they were in 2010, i.e. jobs/population and housing units/population would stay at the noted ratios. There are several factors that could affect either of these ratios as the county population grows. In 2010, the county was still likely feeling the effects of the mid-2000s recession. If this was the case, then the jobs/population ration could be unusually low as many businesses and industries were keeping employment at lower levels. The tough economic conditions during that time could also skew the housing unit/population ratio, as many people sold homes, moved out of the area, or moved in with friends or relatives to save money[61].

Only 30 CBGs were recognized by the ISGM. This meant that the unknown CBG's had to be extrapolated using averages of the known data. The analysis would likely be more accurate if there was up to date data for more if not all of the CBGs.

The future growth scenarios provided by the 2016 New Hanover County Comprehensive Plan gives population growth scenarios, which were used in this analysis. The analysis assumes a uniform spatial distribution of the future population, which was why it was directly correlated with future impervious surface amounts. This scenario is unlikely however as growth would tend to favor certain areas of the county, i.e. areas that are currently undeveloped. A long-term study of expected residential and commercial dwellings would have to be done to estimate a more exact impervious surface amount. Some important factors in this type of study would include single-family vs. multi-family, residential areas, affluence of the communities, commercial areas, industrial areas, and current or proposed zoning regulations.

There are many variables associated with the design and construction of green roofs that may affect their stormwater runoff capture potential. If green roofs were going to be required as part of a stormwater management plan for the county, it would be beneficial to look for further studies in the ideal design to serve the purposes for that particular location. NHC's rainfall patterns and seasonal variations would have to be taken into account. Several designs could be identified, and an in-depth market analysis on construction costs vs. savings could be done to determine at what price points the roofs become cost prohibitive instead of cost effective. This would entail looking at all of the public, private, and social costs of retrofitting current and/or including green roofs in future development.

CONCLUSION:

The analysis shows that even a small inclusion of green roofs in future development can have a significant impact on the stormwater runoff volume within NHC. There are many variables that affect the retention capacity of green roofs and their effects on the overall stormwater management system, but this analysis shows there is enough evidence to suggest that further research is needed and is in the county's best long-term interests. With the expected growth in NHC, incorporating green roofs into permitting requirements, whether through mandates or incentive programs, will almost certainly save money and will be more conducive to future growth scenarios where limited land-space will become an increasingly important planning factor. Additional research is needed into areas where the most population growth is expected and areas where retrofitting traditional roofs in existing developed areas would be most beneficial. Additional research looking at green roofs specifically in a climate similar to New Hanover County and the effects of long-term, multi-day rain events which have the capacity to saturate the soil or growing media on the roofs. The most likely limiting factor for the implementation would be the overall amount of saturation possible for the various green roof designs, and the effect this would have on overall retention capabilities. New Hanover County is also susceptible to extreme weather events such as tropical storms and hurricanes and so options for emergency bypasses or routing to traditional BMPs may have to be considered.

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