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Cost-Benefit Analysis of Green Infrastructure for Sustainable Stormwater Management of the Built Environment

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Abstract

Green infrastructure is a modern network of decentralized stormwater management applications that can capture and infiltrate rain where it falls, thus diminishing stormwater runoff and improving the health of surrounding waterways. While there are unique scales of green infrastructure, such as large swaths of land set aside for preservation. Green infrastructure such as bioretention, green roofs, trees, and permeable pavement is important in today's world since many municipalities are faced with the issues of aging gray infrastructure, impaired local water way, and projected population growth by 2030. Green stormwater infrastructure helps strengthen communities' economy while providing environmentally and economically sustainable solutions to stormwater management issues. This study found that current stormwater runoff issues in municipalities across the United States will be substantially decreased with about 1.05 billion gallons diverted from sewer. This will yield about millions of dollars in annual savings and decrease buildings energy metered water use by 1.37 million kWh of carbon dioxide. Green infrastructure is needed to address and plan for the future impacts of climate change by preventing increased flood risks and public health stresses.

Keywords: Stormwater management, green infrastructure, cost-benefit analysis, BMPs

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1.0. Introduction

Stormwater Management (SWM) is the most common way of controlling the stormwater runoff from impenetrable surfaces such as roofs, parking areas/lots, and driveways. Stormwater runoff conveys pollutants such as nutrients (nitrogen and phosphorus), microbes, heavy metals, and sediments to our lakes and streams (Aladesote &Hunter, 2020). Green infrastructure reduces stormwater discharges by retaining rainfall from small rainstorms, decreasing pollutant loads. Green infrastructure can mitigate flood risk by slowing and decreasing stormwater discharges (Aladesote et. Al.,2022). Stormwater management is important to diminish the sum and speed of overflow across the land and into stream channels, contaminations, and neighborhood flooding. Stormwater management is an effort to decrease the rainwater or melted snow into roads and different destinations and the improvement of water quality, according to the United States Environmental Protection Agency (USEPA). Stormwater management (SWM) includes a wide range of services aimed at environmental protection, enhancement of water resources, and flood control (Aladesote, O. J., & Hunter, J.

2019). When stormwater is soaked into the soil, it is filtered and flows into waterways. Notwithstanding, when heavy rainwater hits, ground immersed by water makes abundance dampness that stumbles into the surface and into storm sewers and street ditches. This water frequently conveys chemicals, microbes, dissolved soil, and different contaminations into streams, wetlands, waterways, and lakes.

1.1 Benefit-Cost Analyses of Green Infrastructure

They introduced the features and gave demonstrations to one specific methodology, benefit-cost analysis (BCA), which is broadly utilized for decision-making in open organizations or public agencies. Previously, choosing project plans or strategy arrangements focused on expenses/cost and proficiency. Today, additional arranging concentrates on an endeavor to measure benefits, including hard-to-monetize benefits that accumulate from exercises, for example, stormwater management. Benefits can incorporate both immediate, like diminished flooding, and aberrant, for instance, expanded land values. BCA is especially pertinent in sustainability planning, where significant objectives can incorporate non-monetized benefits across economic, ecological, and social frameworks. A portion of these may even be challenging to evaluate.

The first step is to estimate the unit cost of each green infrastructure (GI) choice that will be utilized to meet your flood decrease/reduction target. When you determine unit costs for GI choices, you can estimate a total GI scheme cost.

The second step is to estimate the benefits of your procedure. When estimating benefits, it is vital to incorporate damages stayed away from and co-benefits and environment services benefits. While the cost/expense of green infrastructure (GI) is, for the most part, a forthright cost, the advantages of GI choices go on throughout an extensive period, rehashed with each storm event for which GI gives alleviation. Consequently, the economic assessment/financial appraisal of GI methodologies ought to consider yearly advantages and expenses throughout an extensive period. This permits you to determine the point where you "equal the initial investment"- where accumulated benefits surpass gathered costs.

The third step annualizes expenses and advantages of the green infrastructure (GI) methodology over your picked time/frame. The general objective of this progression is to acquire a sense of what the annualized net advantages would be for your GI scheme, which will permit you to make acclimations to the technique to guarantee that your arrangement amplifies the vital benefits of your municipality.

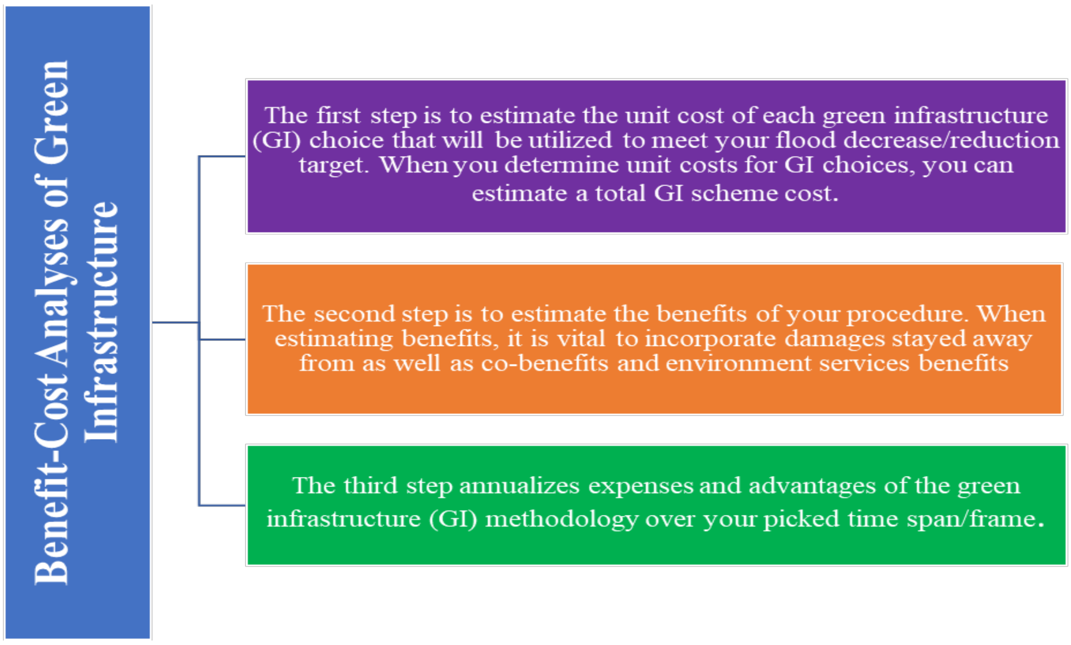


Figure 1. Author's design.

2.0 Stormwater Management Best Management Practices

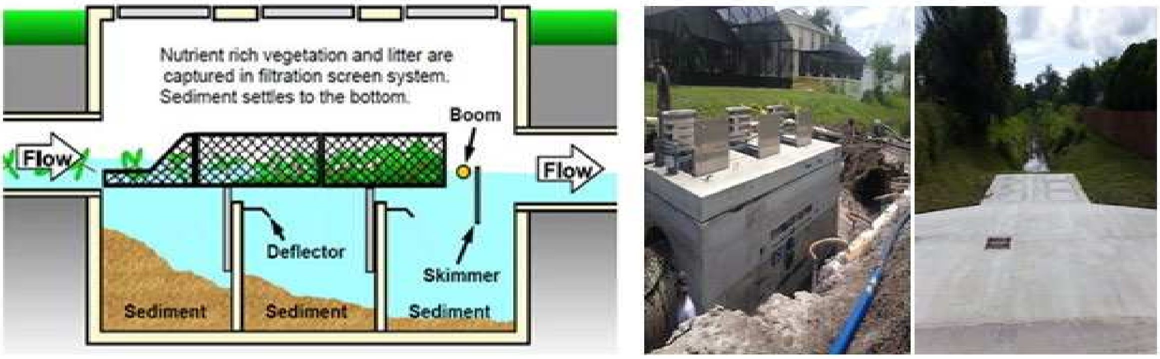
The green stormwater infrastructure provides an opportunity to utilize stormwater best management practices (BMPs). Reducing the effect of flooding in coastal areas is essential for enhancing water quality (England et al., 2001). The best stormwater management practices involve constructing treatment techniques devices such as baffle boxes and incorporating natural filtration methods, which are the green infrastructure.

A 2001 stormwater management study conducted in Brevard County, Florida, showed that different BMPs are economical and applicable to flat topographies. According to the study, the three main suggested economic techniques that have proven effective are the engineering construction of baffle boxes, CDS units, and inlet devices that are efficient for removing nutrients and suspended solids (Aladesote &Hunter, 2020). The maintenance of the baffle box involves the constant use of vacuum trucks for cleaning (England et al., 2001).

2.1Baffle Box for Stormwater Management

The Florida study found that the baffle box utilization is the most successful when used in conjunction with a detention pond to prevent flooding in municipalities. Baffle boxes are concrete or fiberglass structures containing a series of dregs settling chambers partitioned by baffles (USEPA). The average cost for constructing a baffle box is about $425,000. It is a sediment trapping device constructed in line with existing pipes (England et al., 2001). Different chambers within the baffle box function mainly for trapping residues from stormwater and the swivel screen skimmers, which function for waste removal. Baffle boxes are located either in-line or at the end of storm pipes. According to the Brevard County Florida study, thirty-four baffle boxes have been constructed on pipes up to 152.4cm in diameter (England et al., 2001).

2.2 The Design and Mechanism of Operation of a Baffle Box



Baffle Box (Source: Crosstown, 2018)

2.3 Continuous Deflective Separation (CDS) Unit for Stormwater Treatment Technique
Continuous deflective separation (CDS) units are used globally to effectively eliminate contaminants, nutrients, sediments, and heavy metals. The Florida study also proved that the CDS unit is an effective treatment technique for stormwater management. It is an efficient device for sediment and trash removal at Brevard County in Florida. It can also separate debris, oil, and grease from stormwater runoff (Engand et al., 2001). Previous research has shown that the CDS unit screening technology can remove 100% of floating trash (Allison et al. 1998) and 70% of total suspended solids (Walker 1999).
The CDS unit can eliminate about 80% of heavy metal (Ball et al. 2000). Still, according to (Walker et al., 1999), the CDS unit has a poor effect in eliminating total phosphorus (TP) (30%). The stormwater runoffs flow into the CDS units through the inlet pipe to the diversion chamber when rainfalls. The weir guides the polluted water flows into the separation chamber, thereby removing sediments, trash, and debris from the stormwater into the storage litter sump. The stormwater flows into the oil baffle that separates oil, and the stormwater without pollutants flows out of the CDS unit through the outlet pipe into the waterways (Ecoclean, 2018). Its maintenance involves using a vacuum truck to clean the CDS units. Incorporating a CDS unit for stormwater management programs is essential and practical for water pollution control.

Figure:5 (Source: Ecoclean, 2018; Contech Engineered Solutions, 2018)

2.4 Ponds

The stormwater ponds are basins that collect stormwater during flooding and gradually discharge it at a controlled flow rate to avoid flooding and erosion of soil from the encompassing area. It is a form of BMPs for flood control, especially in urban areas, and there are two types of ponds: detention ponds and retention ponds (Williams, Frost, & Xenopoulos, 2013).

3.0 Benefits of green infrastructure

Green infrastructure decreases and treats stormwater at its source, and it provides economic/financial, environmental, and social benefits. The introduction of green infrastructure to supplement the existing gray infrastructure promotes urban livability. Green infrastructure improves water quality and quantity. Water supply: rainwater infiltration practices increase the efficiency of our water supply system. The water infiltrated into the soil can recharge groundwater, an essential water source in the United States. Public and private cost savings: stormwater management with green infrastructure results in developers' lower capital costs/expenses—the savings/investment fund result from lower costs for site grading, paving, and landscaping. Green infrastructure is an overall term alluding to the management of landscapes in manners that produce human and ecosystem system benefits such as

✓ making natural surroundings for birds, butterflies, and other untamed life.	✓ increasing water preservation
✓ Reducing water contamination in the waterways and streams, recharging nearby groundwater.	✓ Reduce the capability of flooding.
✓ Facilitate the development of waste and maintenance frameworks and community beautification,	✓ Delay and lessen top stormwater spillover stream rates.
✓ Decrease disintegration, reduce sewer flood occasions	✓ Increase carbon sequestration.
✓ Reduce metropolitan hotness island impact and energy costs.	✓ Improve air quality and provide extra sporting space.
✓ Develop water quality, and improve human well-being.	✓ Filter overflow contamination.

3.1 Green Infrastructure BMPs

Effective stormwater management at the source to decrease volume, peak discharge, and pollutant loads reduction in stormwater runoff justifies the need for the construction of green infrastructure best management practices (BMPs). The green BMPs primarily used are bioretention, bioswales, and infiltration trenches. Green infrastructure treats stormwater through sedimentation, plant uptake, and filtration (Hoss, Fischbach, & Molina-Perez, 2016; Berland et al., 2017). Green infrastructure is based on infiltration-based technologies, and it is used to manage urban floods at their source (Berland et al., 2017). It is used to manage landscapes to produce benefits for people living in the environment (Keeley et al., 2013). Green infrastructure techniques provide a cost-effective and aesthetically pleasing solution to urban flood management (Keeley et al., 2013). A research study conducted by Berland et al. on the role of trees in urban stormwater management showed that the incorporation of trees into green infrastructure interacts with the urban hydrologic cycle. By intercepting incoming precipitation, removing water from the soil via transpiration, enhancing infiltration, and bolstering the performance of other green infrastructure technologies (Berland et al., 2017). A research study by Keeley et al. showed that green infrastructures such as bioswales and rain gardens assist in creating additional detention capacity on roads, residential properties, and parking lots to diminish stormwater from transportation roads (Keeley et al., 2013).

Furthermore, the management of urban floods and flood pollutants is a major environmental problem in managing the urban landscape. The urban environment has a lot of impervious surfaces that negatively affect the quality of stormwater runoff. It is due to this stormwater runoff on land surface infiltration. These floods from urban areas cause many devastating and damaging effects on urban infrastructures and properties, such as the destruction of habitat, groundwater contamination, sewer system overflow, and water pollution (Xiao, McPherson, Zhang, Ge, & Dahlgren, 2017)
Green infrastructure (GI) solutions can be applied on different scales, from the house or building level to the broader landscape level. The approach to the implementation of a variety of green infrastructure solutions in Howard County that could serve as a model throughout the County will include the following methods: rain gardens, permeable pavements, green roofs, trees and tree boxes, rainwater harvesting systems, right-of-way bioswales, stormwater green streets, blue roofs, cisterns, and subsurface detention systems. The implementation of green infrastructure reduces the volume of stormwater that flows into streams and rivers, protects the natural function of floodplains, and reduces damage to infrastructure and properties.

3.2 Rain Gardens
The rain garden is a landscaped depression with vegetated plants mainly constructed on residential properties that function to decrease the speed of flow of stormwater. It is designed with an engineered soil layer, and the collected stormwater infiltrates into the base soil. Its plants filter pollutants from the stormwater, thereby improving water quality. Credits are given to residential property owners who creates rain garden on their landed property to mitigate stormwater runoff. A rain garden is a form of GI best management practices used to reduce stormwater runoff effects from buildings and decrease waterways contamination (Grehl & Kauffman, 2007).
Establishing a rain garden for individual homeowners is relatively easy. Still, creating rain gardens in the communities, such as in a parking lot, entails setting up starting objectives and stakeholder involvements. A rain garden design entails creating elective flood outlets and assessing soils to about a 6-foot (1.83 m) profundity. Also, oakwood is cut threefold and placed in the seepage area with several mulches spread. Grass strips are planted for capturing runoff and regulating outflows consistently. Rain gardens function to decrease stormwater runoff peak, and the construction of rain gardens could significantly mitigate pollution (Grehl & Kauffman, 2007).

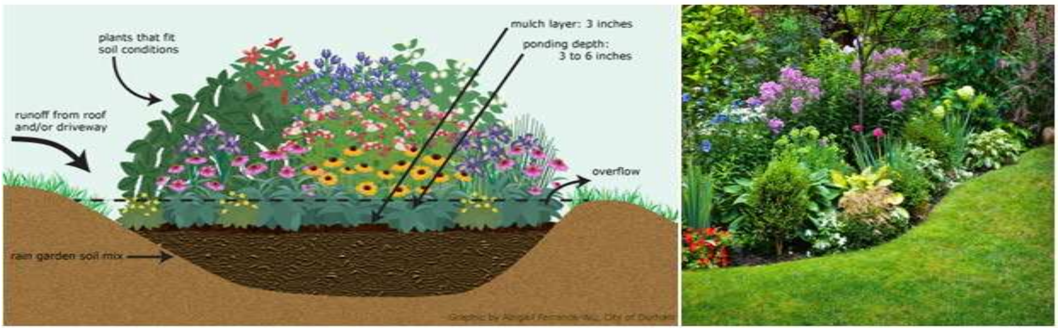


Figure:8 (Source: Durham, NC, 2018; Decor References, 2017)

3.3 Permeable Pavement
Permeable pavement is a high pervious type of surface that filters stormwater runoff through spaces in the pavement surface into the ground through infiltration. There is a different permeable pavement design, such

as porous asphalt, interlocking concrete pavers, and pervious concrete. The structural design of permeable pavement can be made of a surface pervious layer, a conglomerate stone reservoir layer, and a filtration base layer. Parking lots that are constructed with permeable pavement are qualified for credits because it can reduce the peak flow of stormwater based on its infiltration mechanism (Jato-Espino, Sillanpää, Charlesworth, & Andrés-Doménech, 2016).

A 2016 study exhibited that PPS can have a critical effect in measuring runoff produced in an urban catchment. The study showed that PPS has about 40% to 50% volume reduction, and it is an effective system to implement in urban areas because of its multifunctional capacity to delay peak flow (Jato-Espino, Sillanpää, Charlesworth, & Andrés-Doménech, 2016). Another study conducted in Calabria, Italy, described the hydraulic behavior of a permeable pavement designed and constructed at the University of Calabria. The outcome of the study result showed that implementing the dual-porosity model for the base and subbase layers produced a more precise outcome than the single-porosity model and described the hydraulic behavior of pervious pavement (Brunetti, Šimůnek, & Piro, 2016).

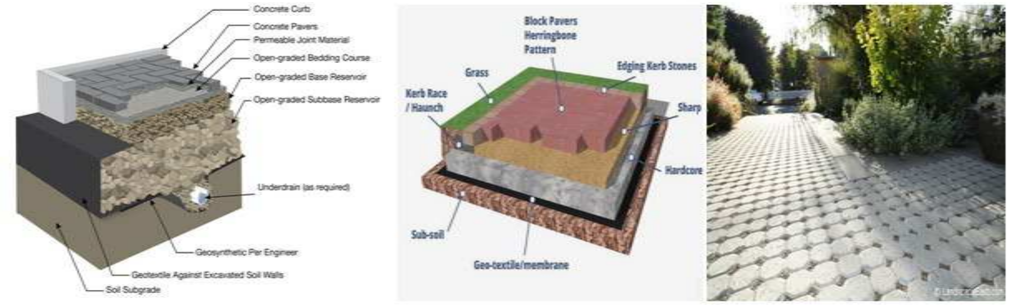


Figure:9 (Source: Smart Prosperity Institute, 2018; Summit Landscapes, 2017; Landscape East & West," 2017)

3.4 Bioswales

Bioswales are vegetated depression land areas designed with plants with soil mixtures to infiltrate stormwater runoff. It conveys stormwater runoff from the roadway and parking lot, and it requires regular maintenance through adequate inspection. It reduces the runoff volume and flow rate, and its infiltration process decreases metals, contaminants, and sediments that boost the economy by reducing water treatment costs. It also serves a recreational purpose because it is aesthetically pleasing when constructed on parking lots.

A research cohort study conducted in Davis, California, to evaluate the effectiveness of two bioswales eight years after construction showed that when compared to the control, the treatment bioswale reduced surface runoff by 99.4% and reduced nitrogen, phosphate, and total organic carbon loading by 99.1%, 99.5%, and 99.4%, respectively (Xiao, McPherson, Zhang, Ge, & Dahlgren, 2017).

Source: (Pinehurst Seattle, 2008; National Association of City Transportation Officials, 2018).

Source: (KC Engineering and Land Surveying, P.C, 2018)

3.5 Stormwater Green streets

Green streets decrease and control the stream of stormwater, specifically at the source, from the adjacent roadway, by gathering overflow in the deliberately designed planted zones so can be slowed down the runoff and consumed before it is transmitted to the more extensive stormwater management system (Weinstein et al., 2008).

(Source: Green and Sustainable Services, 2016)

3.6 Green Roofs

The green roofs are made up of a top vegetative layer that grows in engineered soil incorporated into the top of a drainage layer. It can be of two design patterns, either intensive or extensive, with minimal vegetation. The intensive pattern has thicker soils that support various plants, while the extensive design is covered in only a light layer of soil. Furthermore, green roofs assume an essential function in enhancing the urban territory by advancing the biodiversity, delaying the storm peak to the drainage system, lessening the overflow amount, purifying the air toxins, and the runoff quality (Li & Yeung, 2014).

Figure: 12 (Source: The Nashville Green, 2014).

3.7 Blue Roofs

The blue roofs are designed without vegetation for the primary purpose of detaining stormwater. Weirs at the roof drain inlets create temporary ponding and gradual release of stormwater. A 2014 study proved that green roofs and blue roofs could be used to control stormwater in urban communities. The study showed that the measurement of stormwater runoff outflow from the blue roof was 0.45 l/s while the stormwater outflow from the typical roof was 1.55 l/s (Shafique, Lee, & Kim, 2016).

Figure13: (Source: (EPA, 2017).

3.8 Combined Blue and Green Roof

Both blue and green roofs incorporate both vegetated and non-vegetated methods to decrease stormwater falling off the corrugated roof, thereby controlling stormwater runoff from buildings. It is effective. The green, blue roof from the study is more effective because it could retain more stormwater. The outflow from the green-blue roof was 0.1 l/s, while the control roof was 0.3 l/s. Both roofs effectively reduce peak flow. The result showed that a green-blue roof effectively decreases stormwater downspouts than a blue roof (Shafique, Lee, & Kim, 2016).

Figure: 15 (Source: Discover Magazine)

3.9 Cisterns and Rain Barrels

A rain barrel collects stormwater from the roof and diverts the stormwater through channeled pipes to gardens, flowing slowly through the infiltration method into the soil. Cisterns and rain barrels are watertight receptacles designed to catch and store stormwater off roofs and other impervious surfaces. The cisterns are often larger than rain barrels and can be located underground, ground level, or on an elevated stand. Rain barrels are connected to the existing downspout of a roof and reuse the stormwater for watering plants and other landscaping uses. Runoff problems in the jurisdictions can significantly decrease about 1.05 billion gallons of water diverted from the sewer, which yields millions in annual investment fund savings and reduce energy use by 1.37 million kWh of carbon dioxide (NRDC 2009). A case study showed the use of a 50-gallon rain barrel that is connected to a 25% of 2000 square feet building roof and channeled to a 150 square feet garden was effective in decreasing the stormwater runoff by 2.4–5.4% (Jennings, Adeel, Hopkins, Litofsky, & Wellstead, 2013).

Figure14: (Source: (EPA, 2017).

4.0 Conclusion

Green infrastructure is a cost-effective strategy to improve water quality and help jurisdictions extend their infrastructure investments through the triple bottom line principle that involves the provision of economic, environmental, and community benefits. This research discusses the benefit-cost analysis of green infrastructure, which has both direct and indirect benefits that boost the total economic value of communities. The direct immediate financial/monetary benefits and indirect substantial positive impacts on nations sustainability. Through the evaluation of case studies, this research paper has shown the economic value of green infrastructure that stakeholders can choose for future projects. The overall quality of life and the resilience of communities to disasters can be enhanced with green infrastructure. Future studies should explore further how green infrastructure modeling affect urban renewal for natural disaster prevention.

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