LOW IMPACT DEVELOPMENT (LID) DECISION-MAKING SUPPORT TOOL TO OPTIMIZE POTENTIAL COMMUNITY IMPACT: EVALUATING SOCIO-ECONOMIC BENEFITS THROUGH TRADE-OFF ANALYSES

by

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ABSTRACT

NEETU DONKADA. Low Impact Development (LID) Decision-Making Support Tool to Optimize Potential Community Impact: Evaluating Socio-Economic Benefits Through Trade-Off Analyses. (Under the direction of DR. JAKE SMITHWICK)

Low-impact development practices (LID) have been increasingly recognized for their multifaceted benefits. These practices include swales, green roofs, bioretention systems, and porous pavements. The Environmental Protection Agency (EPA) highlighted in 2007 that LID stormwater benefits enhance ecological sustainability, yield capital, and provide cost savings compared to conventional infrastructure. The current approach only focuses on cost-effectiveness and may not fully capture requirements due to diverse perspectives among stakeholders and implementers. An adaptable and flexible evaluation process is needed to accommodate the dynamic nature of projects. The study proposed a socio-economic framework that enabled an MS Excel-based Decision Support Tool (DST) to bridge this gap between the literature and project implementation.

The effectiveness of the developed DST lies in mediating between various implementers' perspectives, providing insights for decision-making. The outcomes go beyond numbers by offering a framework for quantifying cost-benefit trade-offs and weighing them with project objectives. This study used DST to assess the prospective advantages and costs of two scenarios in South Carolina and North Carolina. In one of the scenarios, the overall cost was $743,083, with a potential savings of $22,971 from the next flood event and a 6.4 out of 10 benefit score for a roadside swale project. This score indicates the selected LID's probability of achieving the prioritized objective of mitigating the flooding challenge. These outcomes from tools can influence decision-making by encouraging a reward-based system revealing trade-offs between economic investments and social benefits.

DEDICATION

I dedicate my effort to my parents, whose unwavering support and selfless contributions have allowed me to pursue my academic goals. To my siblings, Ramya Donkada and Revathi Donkada, I am grateful for your support, which has given me a solid base to build my academic career. I am incredibly grateful to Dr. Jacelyn Rice-Boayue for initiating this research journey and for her guidance. I am grateful to Sunil Diddi for his constant support and belief in me. His presence has given me the courage and motivation to achieve my goals. Thank you for being my pillar of strength and my greatest supporter.

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List of Abbreviations

LID	Low Impact Development
GI	Green Infrastructure
SUDS	Sustainable Drainage Systems
BMP	Best Management Practice
NBS	Nature-Based Solutions
CBA	Cost Benefit Analysis
CEA	Cost Effectiveness Analysis
DST	Decision Support Tool
CNT	Center for Neighborhood Technology
FEMA	Federal Emergency Management Agency
EPA	Environmental Protection Agency
PVCs	Public Value Coefficients

CHAPTER 1: INTRODUCTION

1.1 Background and Context

A low-impact development (LID), commonly referred to as green infrastructure (GI), includes Sustainable Drainage Systems (SuDS), Best Management Practices (BMPs), and Nature-Based Solutions (NBS), aims to manage stormwater runoff, improve asthma conditions, improve property values, and reduce water treatment costs. LIDs are an effective flood management strategy worldwide due to their redundancy, robustness, resourcefulness, and rapidity (Shifflett et al., 2019). Evolution and innovation in construction have increased impervious surfaces for ages, leading to sprawl. Based on the study, it was found that incorporating nature-based solutions in urban settings and utilizing the environmental ecosystem services can be a singular strategy that enables the achievement of 17 Sustainable Development Goals (SDGs) and 44% of its 169 targets (Lombardía & Gómez-Villarino, 2023).

As complex socio-ecological systems, cities face increasing threats posed by resource depletion or natural or human-induced disasters that may occur suddenly, like extreme weather, or slowly, such as gradual economic decline or climate changes (United Nations, Department of Economic and Social Affairs, 2015). A neighbourhood must analyze its resilience to absorb and manage floods caused by increased runoff, develop its capacity, and adapt to many disturbances while maintaining its organization and social, ecological, and economic functions. By incorporating elements such as detention basins, retention basins, permeable pavements, rain gardens, and urban wetlands into urban contexts, cities can reduce flood hazards, improve stormwater management, and reduce the burden on conventional gray infrastructure (United States Environmental Protection Agency (U.S. EPA), 2023). Past project implementation methods prioritize cost-effectiveness over considering the benefits of implementing strategies (Kim & Hyeon Ryu, 2020).

1.2 Benefits of Low Impact Development

LID projects provide a range of benefits beyond the environmental aspect. They are self-sufficient systems that reduce urban heat and balance greenhouse gas emissions, promoting community resilience (Govers, 2016; Boone et al., 2009). Extreme precipitation events can result in floods, but their impacts can be reduced using green spaces (Kabisch, 2017). In addition to their environmental benefits, LID initiatives have significant social and economic advantages that make them an asset for communities (Raucher & Clements, 2010). Environmental justice is a significant concern, especially for low-income citizens and minority groups living in areas with poor environmental quality. However, LID projects have been found to enhance communities by fostering academic growth, creating jobs, improving social interaction and mental well-being, and increasing property values (Center for Neighborhood Technology (CNT), 2020; Tayouga, 2016). LID also promotes energy efficiency by reducing the need for resource-intensive water pumping and treatment, which helps save energy.

Studies have shown that LID can positively impact productivity and reduce respiratory illnesses by decreasing SO_2 and NO_2 emissions, which may also alleviate asthma symptoms providing ecosystem services for occupants (Raucher & Clements, 2010). Moreover, LID spaces act as natural stress relievers, reducing noise pollution and enhancing overall well-being (Shakya & Ahiablame, 2021). These strategies can potentially relieve symptoms of illnesses (Zalejska-Jonsson et al., 2020); when implemented to the highest degree, LID can provide significant social and economic benefits (Locatelli et al., 2020). Therefore, LID planning objectives include enhancing natural interaction, minimizing stormwater runoff, and completely integrating the natural and built environments (Junqueira et al., 2022). By incorporating these practices, LID promotes transparency, trust, public willingness to pay (Raucher & Clements, 2010)., and accountability in decision-making and implementation (Grimmelikhuijsen, 2010).

1.3 Decision Making in Low Impact Development Implementation

LID projects are widely considered as amenities, and including these in city planning can project apathy toward the community and gain the trust of the public (Malek et al., 2019; Schnackenberg & Tomlinson, 2016). The conventional decision-making process for LID often fails to consider the socio-economic impact on the community, leading to non-transparent decisions that can reduce confidence in decision-makers (Grimmelikhuijsen, 2010). Excluding specific stakeholders can also limit their access to information and disempower them from participating in decision-making. To ensure effective and equitable LID implementation, involving the community and considering their needs and concerns is crucial while establishing clear guidelines and standards (Miller & Huber, 2021). However, challenges such as the need for more information, difficulties with evaluating qualitative data, and lack of access to decision-making models and tools can hinder the adoption of LID practices in communities. Decision support tools are necessary to understand technical information on LIDs and estimate the impacts of implementing LID practices (Jayasooriya & Ng, 2014).

1.4 Research Overview

The current study builds upon a previous research endeavour titled "Evaluation of Embedded Benefits for North Carolina Biochar Amended Soil Applications," which utilized the Triple Bottom Line (TBL) framework to evaluate the co-benefits of stormwater Best Management

Practices (BMPs) integrated with biochar-amended low impact development (LID). The research demonstrated expertise in understanding the social, economic, and environmental impacts of LID, including reduced asthma incidence, decreased stormwater treatment needs, and economic advantages like boosted property values and reduced construction and maintenance costs. LID practices, such as retention basins, permeable pavements, and rain gardens, have effectively minimized flood hazards and reduced the burden on conventional gray infrastructure.

The study aimed to convey benefits and score benefits through MS Excel-based decision-support tool (DST) to help designers, engineers, and decision-makers of these LIDs determine how effectively their challenges could be resolved or met. Its dynamic nature also enables future adjustments, catering to diverse user needs and scenarios. This interactivity ensured that the developed tool's outputs evolved with changing inputs, fostering a more personalized and responsive user experience. Furthermore, the study provided outcomes from this DST can serve as evidence for users to dialogue the consideration of socio-economic benefits contrary to conventional cost-based selection. Any static assessment could be inaccurate, unreliable, and impractical as projects are dynamic. Therefore, this DST was designed to be dynamic, exhibiting adaptive features that responded to user inputs and contextual variables.

1.5 Research Objectives

The study aimed to develop a decision-support tool (DST) to assess the socioeconomic benefits of LID practices at a state level before project implementation. This DST was designed to provide a unified framework for evaluating potential co-benefits and extrapolating their approach to derive benefit scoring to evaluate the impact of LID projects in both North Carolina and South Carolina. This DST incorporated socioeconomic metrics and benefits scoring to assess and compare the diverse trade-offs of LID strategies. Its dynamic nature enables future adjustments, catering to diverse user needs and scenarios. The developed decision support tool can assist implementers in evaluating benefits in a quantifiable manner, bridging the gap between literature and project implementation, as illustrated in Figure 1.

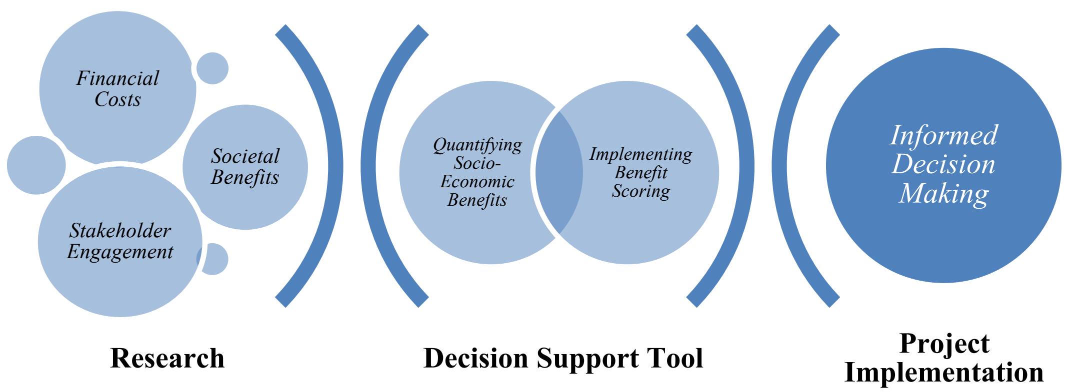


Figure 1 Overview of research

This work was performed through the completion of the following research objectives. (1) Create an MS Excel tool to illustrate potential social and economic community benefits for future North Carolina low-impact development (LID) BMPs, (2) Develop guidance for integrating social and economic metrics into traditional LID BMP's cost-benefit analyses through trade-off analysis and (3) By analyzing case studies from other states, identify potential areas for improvement and future research paths in integrating socio-economic metrics.

The research's first objective aimed to create an Excel-based tool that utilized a socio-economic framework to assess the impact of various LID practices on NC stakeholders. This objective was achieved by identifying metrics to evaluate the social and economic co-benefits of various LID practices that could help in the planning phase of LID. The second objective was to develop a decision framework with a benefit assessment and scoring mechanism that could assist in the decision-making of LID strategies. This tool transformed social and economic metrics by integrating them into a decision-making framework, providing cost-benefit trade-offs. This tool could be used as a guiding factor for designers and implementers to plan and meet project objectives. This framework helped determine the efficiency of LID practices in addressing the challenges with priorities.

Since projects are dynamic, evaluating the metrics differs for sites with specific challenges and priorities, and the final objective aimed to investigate real-world projects conducted in North Carolina and South Carolina that were performed using the developed tool. These case studies showcased how LID could be practically implemented and offered valuable insights into how project objectives, evaluation criteria, and socio-economic factors could impact decision-making. Analyzing trends and understanding how different LIDs influenced outcomes in specific site conditions and community needs provided a perspective on the challenges and opportunities to make reward-based decisions through evidence-based recommendations.

1.6 Organization of Content

Chapter 1 serves as an introduction to this research study, outlining its purpose and objectives achieved. In Chapter 2, an in-depth review of the literature examines the advantages of low impact development, looks at the factors that influence decision-making and its shortcomings, and examines the LID support tools that are currently available. Chapter 3 provides the research's scope and detailed methodology explanation. Chapter 4 presents the decision support tool, its key features, and an overview of the spreadsheet file. Chapter 5 outlines the results from decision support tool scenarios. Finally, Chapter 6 summarizes the study's conclusions, provides valuable insights based on the derived results, limitations, and future research.

CHAPTER 2: LITERATURE REVIEW

2.1 What is Low Impact Development?

Low impact development (LID) is an innovative approach to stormwater management that integrates natural and engineered systems. Using the natural water cycle, LID allows stormwater control at its source, using techniques such as infiltration, rainwater capture, and reuse to restore predevelopment hydrological conditions (U.S. EPA,2022). LID controls, including basins, swales, and permeable pavements, enhance the quality of life by effectively controlling runoff, improving water quality, and providing green spaces, as shown in Table 2.1. To ensure the LID systems remain redundant, it is essential to design them and carry out proactive maintenance considering factors such as accessibility and plant species. A proactive maintenance plan can ensure effective and well-functioning LID systems (Barron et al., 2017; Scholz et al., 2018).

Engineered structures in LID, such as detention basins, imitate ecological processes to reduce the amount of runoff that enters sewer systems. Dry vegetated detention basins are efficient storage units, allowing pollutants to settle after runoff. Moreover, these basins are also used as recreational spaces, enhancing the community's aesthetics. Wet ponds, or retention basins, utilize vegetation to treat contaminated runoff, improving water quality. Swales, which are shallow vegetated channels, help to slow the water flow, promoting infiltration and pollutant filtration. Permeable pavements facilitate natural drainage by allowing water to infiltrate, reducing runoff. Roadside vegetation, such as grass, naturally filters water and aids infiltration. Unlike conventional methods, LID provides These solutions stand out for their minimal maintenance and lower long-term repair costs, making them a more efficient and sustainable choice (Band et al., 2009).

Table 2.1 LID controls and their characteristics (Susdrain, 2023;Waelti & Spuhler., n.d.)

LID Control	Benefits	O&M Cost ($/SF)	Construction Cost ($/SF)	Lifespan (years)	Working Principle
Retention Basin	Stormwater runoff control, Improved quality of water.	1.84	36.93	20 years (CNT, 2009)	" Surface runoff stored in the basin allows increased runoff management" (Waelti & Spuhler., n.d.)
Detention Basin	Reduces peak runoff, increases groundwater replenishment, beneficial thermal effects, and attractive streetscapes.	1.84	36.93	35 years (FEMA, 2022)	" Surface runoff flow is controlled by storing runoff and gradually allowing runoff to be conveyed to local outlets." (Waelti & Spuhler., n.d.).
Swales	Flexible site drainage alternatives can help improve water quality and regulate peak volume.	1.84	36.93	30 years (CNT, 2009)	" Shallow stormwater channel to slow, filter, and infiltrate stormwater runoff" (Waelti & Spuhler., n.d.)
Permeable Pavement	Improved urban design includes pedestrian safety, bike lanes, and public education.	0.04	8.68	25 years (CNT, 2009)	" Paving with porous material enables runoff to flow through it" (Waelti & Spuhler., n.d.)
Roadside Vegetation (Grass)	Effective erosion control can help manage peak water flow and volume.	0.12	0.7	12.5 years (CNT, 2009)	" Surface densely planted with various types of grass designed to slow, filter, and infiltrate runoff" (Waelti & Spuhler., n.d.)

2.2 Role of Low Impact Development in Sustainability

Sustainability is the core principle of LID, which focuses on natural hydrology restoration in urban environments. LID incorporates nature-based solutions like rain gardens, bioretention systems, permeable pavements, and green roofs, enhancing water quality and stormwater management (Barron et al., 2017; Fletcher et al., 2016). Green roofs act as carbon sinks, mitigating the urban heat island effect and absorbing greenhouse gases (Lee et al., 2015). These solutions create multifunctional urban spaces, encouraging leisure activities and social interactions.

Access to nature, an essential aspect of LID, fosters community cohesion and well-being (Zalejska-Jonsson et al., 2020). Rain gardens and bioretention systems enhance urban ecosystems, promoting biodiversity by offering habitats for diverse species (Brom et al., 2023; Boone et al., 2009). LID involves active participation from stakeholders, ensuring urban spaces meet community needs while reducing ecological impact (Lee et al., 2015). These practices replace gray infrastructure, reducing stormwater management costs, enhancing streetscapes, boosting property values, and stimulating the local economy (Zalejska-Jonsson et al., 2020).

LID offers a flexible solution to urban challenges caused by climate change, incorporating diverse techniques while preserving natural features (Lee et al., 2015). Customizable for specific sites, LID emphasizes community awareness and participation in sustainable water management (Barron et al., 2017; Fletcher et al., 2016). Addressing stormwater issues, enhancing biodiversity, and improving citizens' well-being can pave the way for resilient, eco-conscious, and socially inclusive cities (Zalejska-Jonsson et al., 2020). These practices mitigate ecological impacts such as greenhouse gases and local temperatures, offering significant social and environmental benefits.

2.3 Role of Low Impact Development in Societal and Economic Development

LID planning aims to enhance ecological connectedness, lower stormwater runoff, and integrate built and natural environments. LID has numerous benefits that go beyond enhancing the appearance of urban landscapes. Studies have shown that green infrastructure can positively impact property values and the local economy with improved aesthetics, increased biodiversity, and better recreational opportunities (Brom et al., 2023; Gabrowski, 2023; Boone et al., 2009; Kabisch & Haase, 2014). They promote social equity and well-being by encouraging physical activities, reducing stress, and improving mental health (Qureshi & Rachid, 2021; Shakya & Ahiablame, 2021).

By transforming open spaces into LID installations, they encouraged social interaction, which is essential during difficulties like COVID-19 (Kaluarachchi, 2020). LID implementations serve as therapeutic zones for asthma and coronary artery disease. According to Lee et al. (2015), LID spaces improve public health and social spaces, lower rates of respiratory conditions like type 2 diabetes and asthma, foster social capital, strengthen community resilience, and combat social isolation. These benefits can support the health and well-being of residents while promoting economic growth and social equity (Escobedo et al., 2018; Wolch et al., 2014).

In urban environments dominated by privatization, public parks emerge as essential communal spaces, fostering social engagement and ecological benefits. LID installations address urban issues like unequal access to recreational areas and rising risk exposure in neighborhoods, offering crucial ecosystem functions such as temperature regulation, pollution mitigation, and reduced stormwater. These address climate change stresses, aging infrastructure, and socioeconomic changes (Junqueira et al., 2022). Engaging students in hands-on LID projects can cultivate a strong understanding of environmental sustainability, turning them into community stewards. Despite widespread LID adoption for Clean Water Act compliance, research gaps persist in understanding how LID strategies can be specifically tailored to cater to diverse neighborhood needs (Junqueira et al., 2022).

We live in a rapidly changing world, which makes it challenging to find that balance between economic growth and environmental protection. Unfortunately, many city planning policies do not consider the long-term benefits of investments. Despite these challenges, the concept of LID stands out as a practical approach that alleviates societal and environmental stresses by promoting resource management (Shifflett et al., 2019), enhances community well-being, and creates opportunities for economic growth by supporting and promoting local businesses. LID strengthens safety initiatives and community security (Shakya & Ahiablame, 2021) and improves property values depending on the choice of controls.

LID significantly enhances a region's economic vitality by directly contributing to Gross Value Added (GVA). It bolsters the region's reputation, attracting high-value businesses, entrepreneurs, and skilled workers, ultimately reducing unemployment and boosting GVA (Natural Economy NorthWest (NENW), 2008). LID boosts property values and local businesses, enhances employee productivity, and reduces healthcare costs by providing greener, more pleasant workplaces that lower stress levels, resulting in decreased sickness and absenteeism (Qureshi & Rachid, 2021). High-level personnel are more likely to remain in their jobs for longer when the physical environment is inviting (Kabisch & Haase, 2014), which reduces the expense of acquiring and training new staff.

Compared to typical grey infrastructure, LID practices are more energy-efficient and effective at reducing the danger of flooding, as demonstrated by their ability to reduce stormwater runoff (Locatelli et al., 2020). The cost-effectiveness of implementing LID depends on several variables, such as project size, location, site variables, and choice of LID practices (Locatelli et al., 2020). The expenses shown in Table 2.2 illustrate how choosing the LID approach affects upfront and ongoing expenditures (CNT,2009). Unstable soil conditions may cause early costs to increase, but when LID is applied site-specifically, ecosystem services can produce significant advantages that offset these initial costs (Kaluarachchi, 2020).

Table 2.2 LID controls with associated initial and maintenance costs (CNT,2009)

LID CONTROL	Construction Cost ($/SF)	Maintenance Cost ($/SF)
Detention Basin	36.93	1.84
Retention Basin	36.93	1.84
Swale	36.93	1.84
Permeable Pavement	8.68	0.04
Vegetation (Grass)	0.7	0.12

Studies indicate that LID often emerges as a cost-effective substitute for conventional gray infrastructure methods (Escobedo et al., 2018; Hejazi et al., 2019). Existing LID projects demonstrate cost savings as LID projects can be modified to match site-specific requirements instead of conventional infrastructure. LID projects may have higher initial costs, but their overall costs, such as operation and maintenance, may be less than conventional infrastructure. If LID projects combine benefits from ecosystem services with financial benefits, they will often be financially advantageous (Venkataramanan et al., 2019). Rethinking traditional infrastructure can reduce the amount of water required and the extent of treatment needed. By employing these strategies, stormwater and combined sewer overflow systems, including pipes, storage, and treatment devices, can be effectively managed without relying on traditional grey infrastructure (Lee et al., 2015).

The value of reducing grey infrastructure using the benefits transfer method facilitates the evaluation of savings from LIDs (Jayasooriya & Ng, 2014). One approach to valuing the reduction in stormwater runoff for these communities is the averted cost method. The reduction in runoff value equals or exceeds the cost incurred by the local stormwater utility for treating that runoff (Raucher & Clements, 2010). The savings obtained through LID techniques depend on factors such as soil types, rainfall patterns, peak flow rates, and local material costs. Implementing LID techniques can benefit the economy by combining visitor attractions, preserving beautiful landscapes, and promoting economic activities in various sectors such as agriculture, forestry, public services, and hotels. This LID can support tourism, retail, and recreation while improving air quality and property values (Schnackenberg & Tomlinson, 2016).

Integrating LID into city planning is appealing in growing developments and is often projected as an exclusive amenity (Liao et al., 2018; Sharma et al., 2019). Outdated stormwater regulations in many regions often hinder the adoption of LID strategies (Clar, 2004). Overcoming these challenges requires supportive policies and regulations mandating or encouraging LID use in new development projects, backed by public-private partnerships, community engagement, and incentive-driven policy frameworks (Escobedo et al., 2018; Fletcher et al., 2016; Hejazi et al., 2019; Wolch et al., 2014). Based on Grimmelikhuijsen (2010), establishing financial accountability starts with transparent decision-making processes and budget allocations based on long-term costs and benefits that improve resident well-being.

2.4 Decision Making in LID Implementation

LID practices have emerged as a promising approach to mitigate the negative impacts of urbanization, such as water pollution, urban heat, flooding, and air pollution (Grabowski, 2023). The implementation of LID faces several challenges because of the complex process with multiple objectives related to ecological protection, economic viability, social equity, and public wellbeing (Kaluarachchi, 2020). Several stakeholders are considering LID to address sustainable urban drainage systems and water-sensitive urban design (Grabowski, 2023). However, traditional decision-making process often prioritize cost-effectiveness, neglecting the multifaceted co-benefits of LID (Hansen et al., 2019).

A significant obstacle necessitates a change from customary methods. Cognitive obstacles and worries about dependability, liability, expenses, performance, and maintenance are to blame for this. A variety of factors must be taken into account when making complex decisions, including long-term performance, maintenance requirements, funding mechanisms, stakeholder engagement, data availability, and adoption barriers. But one problem is the lack of information and resources for assessing LID practices, especially when it comes to the social dimensions (Wellmann et al., 2023). As solutions, innovative policy interventions and educational initiatives have been suggested (Grabowski, 2023; Shifflett et al., 2019). Through collaborative problem-solving and interdisciplinary collaboration, LID can be effectively incorporated, guaranteeing sustainable operations.

A collaborative and multi-stakeholder approach is necessary, considering various objectives related to ecological protection, economic viability, social equity, and public health. However, there are several challenges for LID implementation, including cognitive barriers, lack of comprehensive data and tools, and reluctance to shift from traditional practices. To overcome challenges, a multi-objective framework that transparently integrates various criteria and involves stakeholders is needed (Kaluarachchi, 2020). Such frameworks require combination of analyses to evaluate criteria and inform stakeholders of project outcomes, as shown in Table 2.3.

Table 2.3 Economic analyses comparison

Analysis Type	**Cost-Benefit Analysis (CBA)**	**Cost-Effectiveness Analysis (CEA)**	**Trade-Off Analysis**
Definition	An economic evaluation method compares a project's total costs and benefits to determine its overall desirability, maximizing net benefits.	An economic evaluation method that compares the costs of alternative projects with their effectiveness (outcomes) in achieving a cost-effective alternative.	A clear and strategic method is used to analyze and evaluate conflicting objectives involving multiple stakeholders to find optimal solutions considering factors.
Application	By juxtaposing projected or estimated costs and benefits, it determines if the potential benefits of building LID surpass the financial burdens involved (Liu et al., 2016).	When assessing the adoption of LID, cost-effectiveness analysis enables a comparison of expenditures with outcomes (benefits) evaluated in natural units (Montalto et al., 2007).	When there are conflicting objectives, stakeholder preferences, and limited resources, it is helpful to analyze the potential impacts of LID strategies (Sidarus et al., 2019; Hansen & Pauleit, 2014).
Limitation	Assigning dollar values to intangible costs is a challenging task. This process requires accurate data and assumptions to place a dollar value on services that are not easily quantifiable, such as groundwater recharge (Keating & Keating, 2014; Liu et al., 2016).	The effectiveness measure may not fully capture all relevant dimensions of a project's impact. Some non-monetary outcomes might be overlooked (Montalto et al., 2007).	The accuracy of available data and stakeholder inputs impact the outcome. Identifying and weighing criteria for the trade-off analysis can be subjective, which may not always result in a definitive solution (Hansen & Pauleit, 2014).
Pros	Considers quantitative and qualitative benefits and costs	Identify the most efficient option to ensure the optimal use of resources.	Considers multiple criteria, stakeholder preferences involve multiple stakeholders (Kim & Hyeon Ryu, 2020), facilitating transparency in the decision-making.

Trade-off analysis is a valuable approach for decision-making in LID implementation. It evaluates the benefits and drawbacks of each LID method based on factors such as effectiveness, budget, equity, and environmental justice. The analysis aims to determine the preferred alternative that mitigates challenges. Theoretical frameworks guide decision-making by focusing on behavior, processes, and principles. Multi-Criteria Decision Analysis (MCDA) can compare LID controls and assess their contribution to promoting criteria in selected locations.

2.4.1 Review of LID Support Tools

This study analyzed LID support tools presented in Table.2.4. The Stormwater Management Model (SWMM) has a design focused on the effectiveness of LID to improve the quality and reduce the quantity of runoff water (Khader & Montalto, 2008; Rossman, 2010). The CNT Green Values Calculator is a cost-effective tool that facilitates stormwater management. Users can select various LIDs to achieve runoff reduction goals while considering benefits such as increased real estate value and groundwater replenishment (CNT, 2009).

The NBS Selection Tool recommends LID practices, such as urban trees and sustainable urban drainage systems (SUDs), based on objectives and criteria (Croeser et al., 2021). This tool incorporates expert opinions on the efficiency of LID, addressing challenges and providing decision-making, including identification of barriers (Urban Green UP, 2021). The Mersey Forest's GI Valuation Toolkit evaluates ecosystem services' economic and social worth, including climate regulation, biodiversity, tourism, and more (GiVAN, 2010).

Table 2.4 Features, benefits, and contributions of reviewed tools

Tool Name	Owner	LID Supported	Purpose	Reference
EPA Stormwater Management Model (SWMM)	United States Environmental Protection Agency	Bioretention, Infiltration Trenches, Porous Pavement, Rain Barrels, Vegetative Swales, Green Roofs, Street Planters, Amended Soils	To organize, develop, and assess the efficacy of various GI in runoff quality improvement and quantity reduction	(Khader & Montalto 2008; Rossman, 2010)
Centre for Neighbourhood Technology (CNT) Green Values National Stormwater Management Calculator	Centre for Neighbourhood Technology, Chicago	Green roofs, planter boxes, rain gardens, cisterns, native vegetation, vegetation filter strips, amended soils, swales, trees, permeable pavements	The selection of runoff reduction goal and combination of GI provides the optimum runoff reduction cost-effectively.	(Centre for Neighbourhood Technology,2009)
NBS Selection Tool	Urban Green UP	SUDs, Urban Carbon Sink, Urban Trees, Urban Catchment Forestry, Urban Garden Biofilter, Urban Orchard, Vertical Garden	Based on prioritized objectives, this tool offers recommendations with barriers.	(Croeser et al.,2021; UrbanGreenUP,2021)
GI Valuation Tool Kit	Mersey Forest	Green cover	Evaluate the dollar value of the environmental and social benefits of GI	(GiVAN 2010)

CHAPTER 3: METHODOLOGY

3.1 Scope of Research

This study examined the benefits of specific LID practices in North Carolina and South Carolina utilizing a tool also developed as part of this work. This study explored the different dimensions of LID, including its environmental, socio-economic, and public health implications. The study aimed to provide valuable insights into the challenges, benefits, and decision-making associated with LID initiatives. This was achieved through a systematic review of literature, tool development with embedded frameworks, and scenario analyses. The study covered various aspects, such as financial considerations, societal impacts, and decision support tools, to understand the role of project objectives in outcomes. This study utilized a developed tool to examine the benefits of specific LID practices in North Carolina and South Carolina. The tool included detention, retention, permeable pavement, vegetation, and swale. Overall, the study aimed to provide a detailed understanding of LID and its implications, offering targeted recommendations for sustainable urban development.

3.2 Research Methodology

The research involved three phases to achieve objectives, as shown in Figure 2. Phase 1 was a systematic literature review establishing a theoretical framework to identify measurable metrics for the socio-economic framework. Phase 2 included socioeconomic factors into scoring to evaluate the effectiveness of LID chosen in mitigating the targeted challenges utilizing a Decision Support Tool (DST), with the goal of transforming this framework into a helpful resource for decision-making. In Phase 3, the framework was applied to real-world scenarios in DST, providing valuable insights into its practical application.

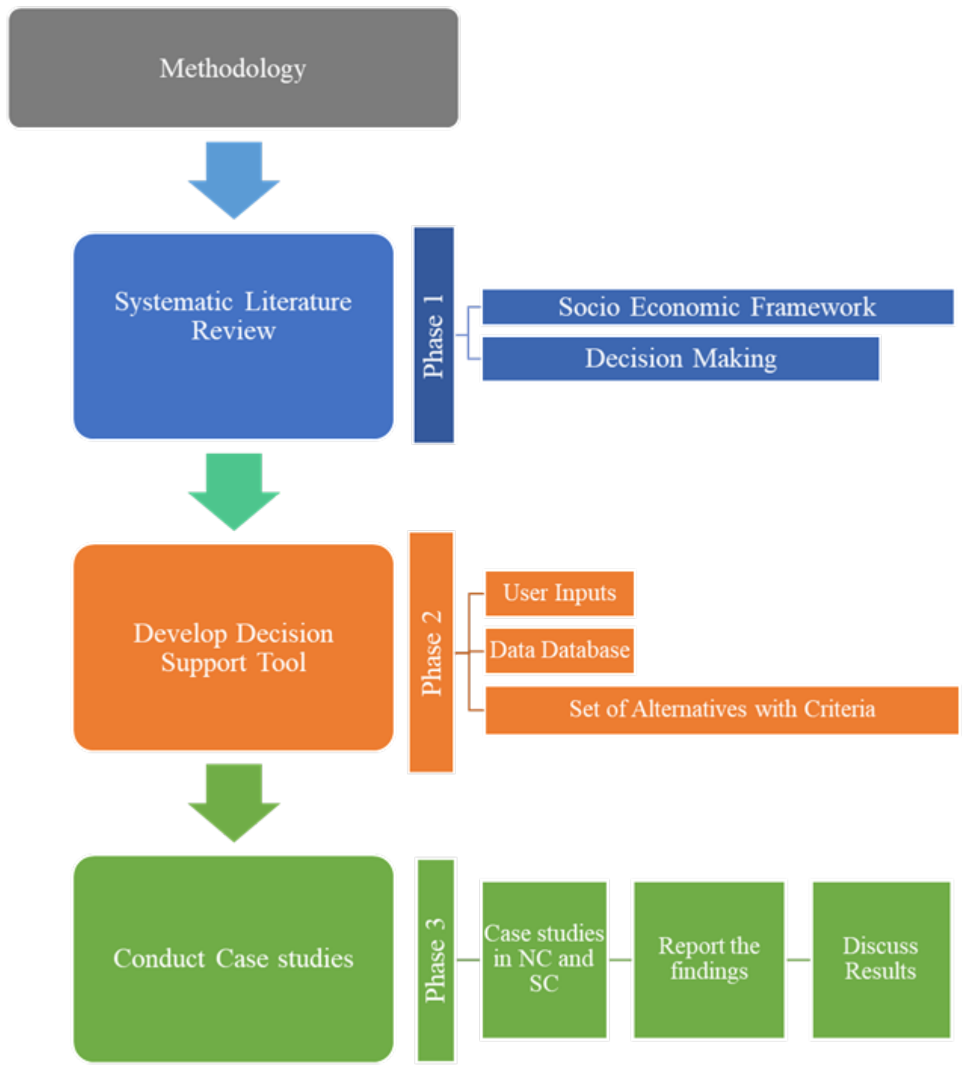


Figure 2 Research methodology flowchart

In Phase 1 of the study, a comprehensive literature review was conducted from critical databases, including academic journals and electronic databases with keywords such as low impact development, socio-economic benefits, social impacts, economic analysis, and decision-making. The research aimed to develop an Excel-based tool with a theoretical framework that translated literary socio-economic metrics into quantitative metrics for evaluating their impact on the community, as shown in Figure 2.

Phase 2 involved developing a decision framework that integrated the theoretical framework from Phase 1. This framework enabled users to input project-specific data, including location at the county and census tract levels and LID details. The identified socio-economic metrics, such as economic costs and property value enhancements, are intertwined with a decision support framework that quantified and calculated benefit scoring through metrics, as shown in Figure 3. Phase 3 evaluated the effectiveness of LID practices in two scenarios, achieving socio-economic objectives related to socio-economic outcomes as shown in Figure 3. The first case study focused on the. Fox Hollow development project on James Island, SC. The second case study chosen was Westfield Level Spreader in Charlotte, NC. These scenarios involved evaluating the impact of these implemented projects on the community utilizing DST. These scenarios were necessary to demonstrate the applicability of DST and the likelihood of accomplishing the scenarios' intended objectives and illustrating any potential co-benefits.

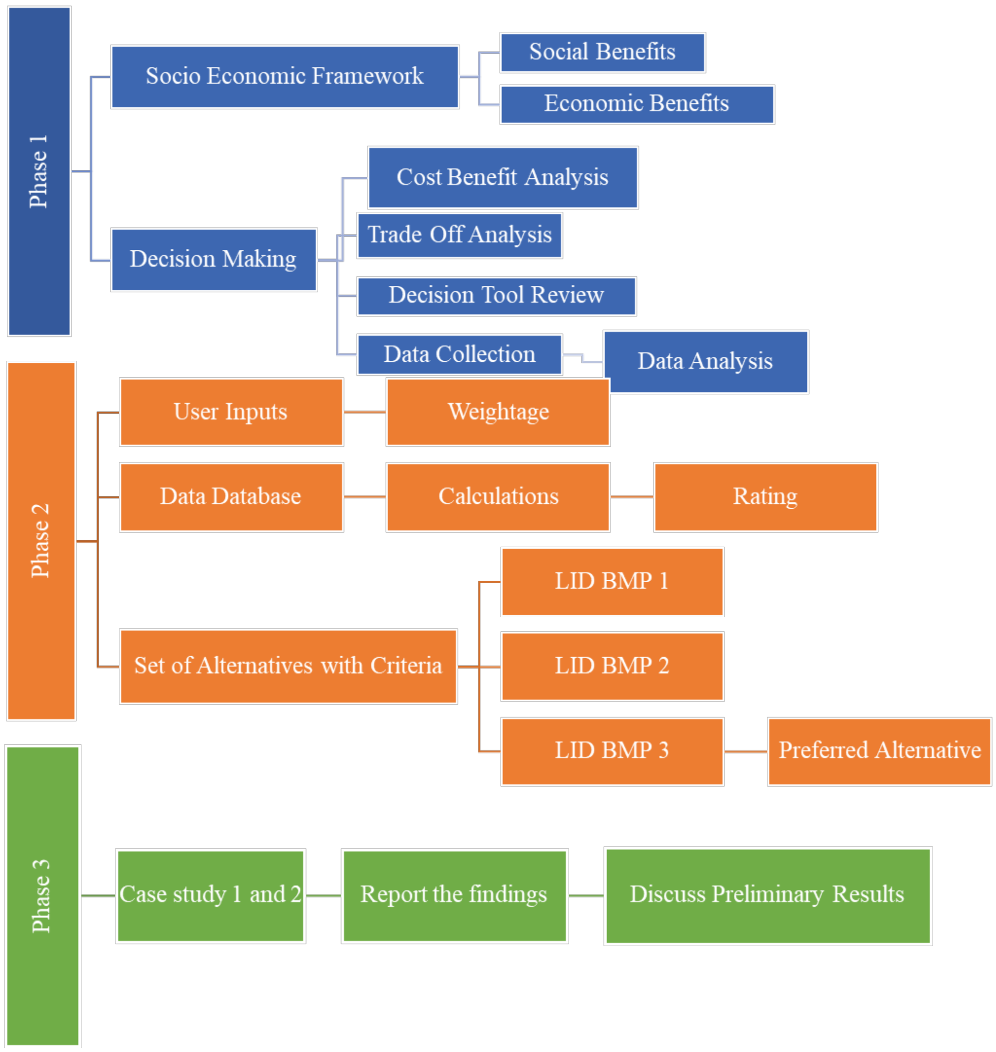


Figure 3 Breakdown of phases in methodology

3.3 Decision Support Tool

3.3.1 Socio-Economic Assessment Framework

The Socio-Economic Assessment Framework shown in Figure 4 provides a systematic approach for evaluating the co-benefits of LID projects in North Carolina. This comprehensive framework encompasses a range of equations to assess the potential impacts of LID practices on a community's social and economic dimensions. Through the integration of relevant data, the framework enables users to quantify and understand the benefits and costs of LID measures. This framework was created with community well-being, recreational opportunities, and financial considerations. Moreover, this framework is pivotal in optimizing the quantified co-benefits for selecting LID.

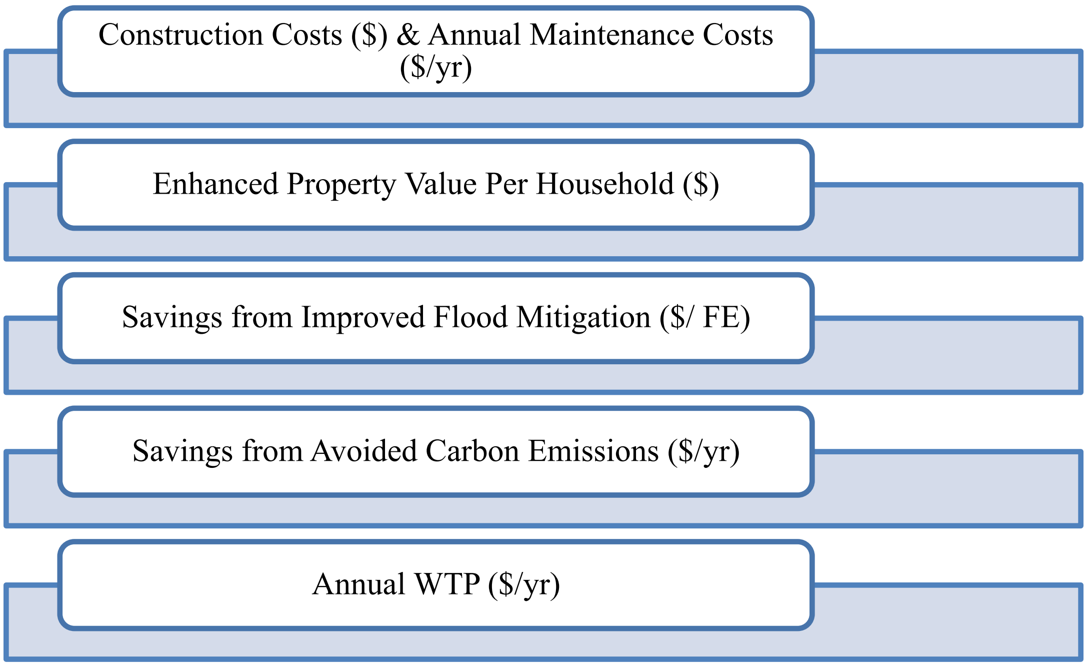


Figure 4 Socio-economic framework to evaluate low-impact development alternatives

A) Social Metrics

As shown in Table 3.1, the community received multiple social benefits from LID controls. One is that assessing co-benefits over time increases public confidence in the initiative's governance and improves social acceptance. Implementing LID reduced carbon dioxide emissions, promoting quality of life (Raymond et al., 2023). By fostering public commitment and lowering carbon emissions, LID projects helped to fortify social cohesiveness (Lee et al., 2015; Gabrowski, 2023) and restore ecological sustainability (Locatelli et al., 2020). Based on the user inputs, the model generated estimates from literary inputs in the tool to calculate these social metrics listed below employing the specified methods to determine their values.

Table 3.1 Metric framing for social benefits

Social Benefit	Prior Studies and Published Datasets
Willingness to Pay	Wong & Montalto (2020) Wang et al. (2022) Raucher & Clements, (2010) American Community Survey (ACS) (2010) Zalejska-Jonsson et al. (2020)
Savings from Avoided Carbon Emissions	FEMA (2022)

I) Willingness to Pay (WTP)

WTP, derived from resident preferences and exposure to various LIDs, is the proportion of a population that values LID installation. According to Wong and Montalto (2020), WTP for LID was based on a combination of two critical factors: the location's population (Pop) and the Public Value Coefficient (PVC). A higher value indicated the proportion of people who appreciate nearby LID practices and are willing to pay for LID installations, indicating a more significant potential for the success of LID projects.

Since showcasing the tool's features was the main goal, some assumptions had to be made, which could have resulted in deviations from results based on the selected location. Based on the research of Wong and Montalto (2020), permeable paving was categorized as permeable playgrounds, detention basins, roadside swales, and retention basins as bioswales. Furthermore, roadside vegetation (grass) was assumed to be the category of public parks. Wong and Montalto (2020) conducted in New York, showed the Public Value Coefficients (PVCs), as shown in Table 3.2. Raucher and Clements (2010) discussed an expenditure of $15 yearly per household for water quality and aquatic habitat improvements, realizing the benefits of installations conducted in Philadelphia. While the study focused on North Carolina and South Carolina, these assumptions were made to illustrate how the DST could compute metrics in areas where data was unavailable.

To calculate the WTP Equation 1, the population at the selected location obtained from the ACS survey with a five-year interval is multiplied by the PVC, and the cost. This approach quantified the potential socio-economic benefits and assessed the community's perceived value for the chosen LID initiative.

Table 3.2 Aggregate Public Value Coefficients (PVC) by LID Type

LID Type	PVC
Permeable Paving	0.25
Roadside Swale	0.52
Retention Pond	0.52
Roadside Vegetation	0.57

Equation 1

$$WTP_{wq} = Pop \times PVC \times C_A$$

Where:

Pop represents the population at the selected location.

PVC refers to the Public Value Coefficient, which is the perceived value of acceptance associated with the LID selection by a community at a specified region.

C_A represents the households' annual social commitment cost for water quality and aquatic habitat improvements.

II) WTP for Recreational Areas

This metric defines the community's commitment to obtaining recreational benefits (Wang et al., 2022). Since showcasing the tool's features was the main goal, some assumptions had to be made, which could have resulted in deviations from results based on the selected location. This assumption was made to illustrate how the DST could compute metrics in areas where data was unavailable. As per Wang et al. (2022) conducted in China, the cost associated with obtaining these benefits was assumed to be \$10.80 to evaluate this metric.

Population data for the assessment was obtained from the American Community Survey (ACS), covering five-year demographic data on households at the census tract level. This approach allowed for an evaluation of the willingness to obtain recreational utilizing Equation 2 to enhance ecosystem services to the population.

Equation 2

$$WTP_R = Pop \times Cost\ for\ Recreational\ Benefits\ per\ SF$$

III) Savings from Avoided Carbon Emissions

These metrics measured energy savings from green infrastructure and reduced carbon emissions produced by equivalent gray infrastructure. They were using the assumed value from eliminating carbon dioxide emissions, as reported by FEMA, to derive cost savings on LID implementation. According to FEMA (2022), avoided costs of CO_2 emissions were quantified from reduced wastewater pumping because of stormwater capture by LID controls, as shown in Table 3.3. This metric assumes values from the FEMA report as the unit price per square foot, as shown in Table 3.3, to calculate costs using Equation 3.The annual avoided costs were calculated by multiplying the LID control's footprint and the value of avoided carbon emission by LID type.

Table 3.3 Value of avoided carbon emissions by LID Type (FEMA,2022)

LID Type	Value of Avoided Carbon Emissions ($/SF/Yr)
Permeable Paving	0.003
Roadside Swale	0.02
Retention Pond	0.02
Roadside Vegetation	0.01

Equation 2

$$Annual\ \ Savings\ from\ Avoided\ Carbon\ Emissions\ = (LID\ Footprint) \times \left(\frac{CO_2}{Emissions}\right)$$

Where:

$LID\ Foot$= Square footage of LID selected

$\left(\frac{CO_2}{Emissions}\right)$ = Value of Avoided Carbon Dioxide Emissions per Square Feet (FEMA, 2022).

B) Economic Metrics

Economic metrics were considered the financial costs and benefits incurred by LID implementation and were incorporated into the tool utilizing three metrics, detailed in Table 3.4. Metrics for costs included construction costs, maintenance costs, enhanced property values, and Improved flood mitigation. Based on the user inputs, the model generated estimates from literary inputs in the tool to calculate these economic metrics listed below employing the specified methods to determine their values.

Table 3.4 Metrics framing for economic costs and benefits

Economic Benefit	Prior Studies
Low Impact Development (LID) Costs	CNT (2009)
Enhanced Property Values	CNT (2020)
	Braden et al. (2010).
	Zillow (2022)
	National Association of Realtors
Improved Flood Mitigation	NIBS (2018)
	FEMA (2023)
	Grabowski (2023)

I) Low Impact Development (LID) Costs

LID construction and maintenance costs have been calculated using Equation 4, where unit price values are assumed to be the Center for Neighborhood Technology (CNT) Green Values Calculator. The construction costs for each LID practice are estimated by considering project-specific factors like site conditions and footprint acquired from user inputs, which are then multiplied by the construction and maintenance costs of the LID practices, as mentioned in Chapter 2 (CNT, 2009).

Equation 4

$$Construction\ Costs = Unit\ Cost\ \times Footprint\ of\ LID\ BMP$$

$$Maintenance\ Costs = Unit\ Cost\ \times Footpint\ of\ LID\ BMP$$

$$Total\ Costs = Construction\ Costs + Maintenance\ Costs$$

II) Enhanced Property Values

The potential influence of LID installation is seen to increase neighbouring property values. Based on the user-defined location, the tool can estimate the maximum increase rate of property values. The maximum increase in property value rates for each LID alternative was assumed based on Green Stormwater Infrastructure Impact on Property Values by CNT, as shown in Table 3.5. The property values data include median property values from Zillow, the National Association of Realtors. The median property value is multiplied by the maximum increase rate to determine the expected growth in property values over time per household, as shown in Equation 5. The outcome represents the annual percentage growth in property values.

Table 3.5 Increase rate of property values by LID Type

LID Type	**Max Property Increase rate (%)**
Permeable Paving	0.23%
Roadside Swale	0.69%
Retention Pond	0.23%
Roadside Vegetation	0.69%

Equation 5

$$Property\ Value\ \ Increase = \ Current\ Property\ Value\ \times\ \ Property\ Increase\ Rate$$

III) Improved Flood Mitigation

LID could reshape socioeconomic issues, such as intensifying unequal exposure to environmental hazards like flooding. The flood risk percentile was assumed from the FEMA National risk index dataset 2023, the national percentile ranking of the community’s component value compared to all other communities at the same level. A higher percentile indicated a lower flood risk, leading to higher cost savings in flood mitigation efforts. This metric assumed that for every $1 spent on flood risk reduction, $6 was saved on future disaster losses (NIBS, 2019). Refer to Equation 6 for determining cost savings from flood mitigation as follows:

Equation 6

$$Cost\ Savings\ from\ Flood\ Mitigation = LID\ Intitial\ Costs\ \times 6 \times (100 - Flood\ Risk\ Percentile)\%$$

The Flood Risk Percentile represented the national percentile ranking of the community's vulnerability to flooding.

3.3.2 Integrated Decision Framework

This developed decision-making support tool utilizes a unified framework employing partial cost-benefit analyses and trade-off analyses to help stakeholders recognize the benefits of the LID options. The trade-off analysis compared the structured framework's outcomes and scenarios based on their outcomes, promoting transparency and discussions among decision-makers while reducing the impact of personal biases on criteria. According to Sidarus et al. (2019), this systematic framework helps implementers assess if they have achieved their objectives.

Multi-Criteria Decision Analysis (MCDA) was employed to implement the trade-off analysis concept in a decision-support tool (Croeser et al., 2021). As part of the framework, potential challenges and metrics were identified, as shown in Figure 5, enabling the verification of economic feasibility aligned with the socio-cultural benefits of LID. These challenges and criteria that guided the decision-making process were identified. A significant deliverable required for developing LID practices was to address a range of typical urban problems, such as flooding, awareness, health and well-being, and social equity. These criteria were quantitative and utilized to verify aligned outcomes with the user's goals.

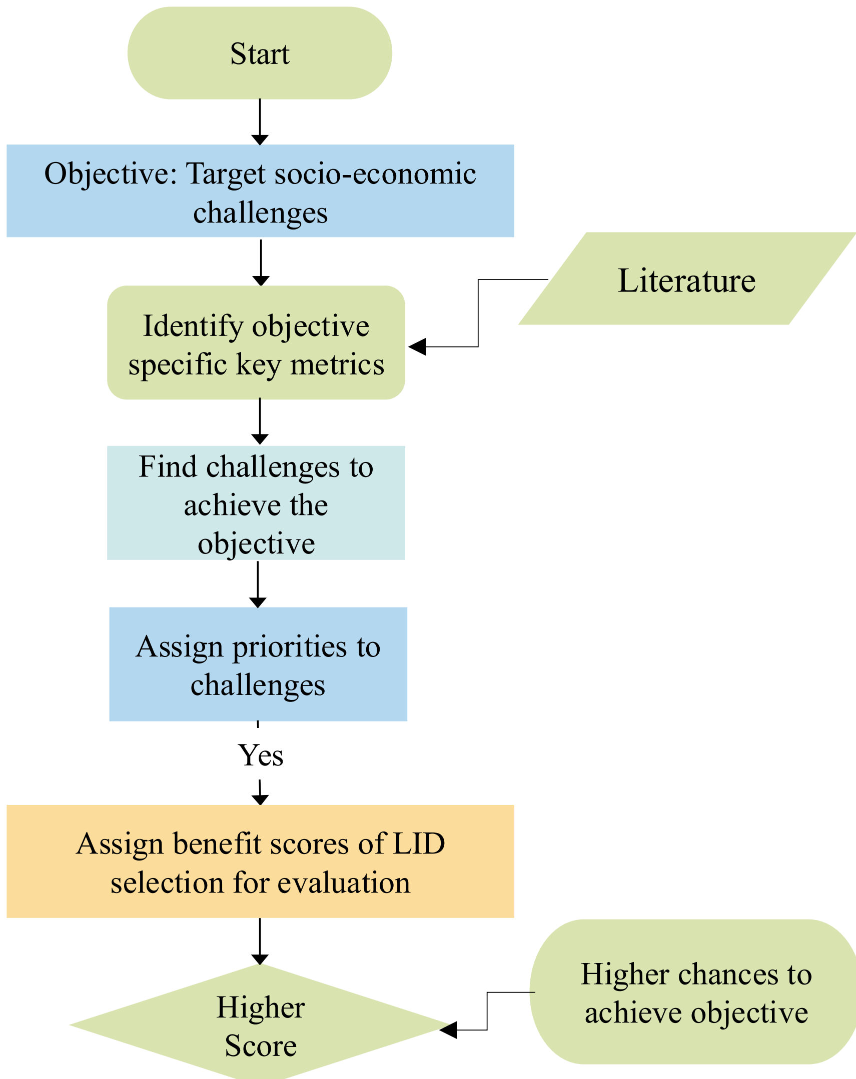


Figure 5 The process of decision support tool.

The tool with multi-criteria decision analysis (MCDA) guided LID selection and addressed multiple objectives, as shown in Figure 6. The MCDA method was transparent, with several considerations at required levels of significance, and it was used in various scientific fields to systematically evaluate, score, and rank multiple alternatives against criteria, assisting decision-makers in various applications. This technique involved the step-by-step procedure shown in Figure 6 to create and use the MCDA to evaluate LID BMPs in DST.

Figure 6 The methodology for tool utilizing MCDA to evaluate costs and benefits of LID.

LID BMP Alternatives: Compile all feasible alternatives that might be considered. In this instance, four different LID BMP types, such as retention basins, detention basins, swales, permeable pavement, and roadside vegetation (grass), were be supported by this tool.

Define the Challenges: Standard challenges were established by which LID BMPs were juxtaposed. These requirements were drawn from the project's context and the region's conflicting objectives. Flood mitigation, the provision of green space, community well-being, employment generation, and other pertinent elements may be included as criteria.

Data Collection: This study compiled all the pertinent data from multiple trustworthy sources and presented it in Table 3.6. These were further segregated into LID-wise cost and benefit value, census tract, and county-wise data.

Table 3.6 Summary of data sources

Data Sources	Description
Wong and Montalto Survey (2020)	Data on Public Value Coefficient (PVC) from a survey to determine residents' preference for LID
Center for Neighborhood Technology (CNT) GSI impact on property values (2020)	Data on real estate sales data with geocoded information on installations from Seattle and Philadelphia according to LID type.
Zillow, National Association of Realtors (2022)	Data on median property values per county in North Carolina
Behavioral Risk Factor Surveillance System (BRFSS) survey (2019)	Self-reported data on the prevalence of asthma at the county level
American Community Survey (ACS) (2010)	Data on 5-year intervals county-level and census tract level population in North Carolina.
Center for Neighborhood Technology (CNT) Green Values Stormwater Management Calculator Methodology (2006-2020)	Data on cost estimates for construction and maintenance of green infrastructure
Federal Emergency Management Agency (FEMA) (2023)	Data on risk index scoring offering insights into 18 natural hazards' impact on communities by county

Evaluation and Scoring: Created a scoring system to compare the performance of each LID. This scoring system converted qualitative and quantitative data into numerical values for comparison.

The weighting of the challenges: The default weighting distribution in MS Excel followed a balanced distribution of priorities consistent with decision-making. The hierarchical weights followed a progressive pattern, with the top priority set objective receiving the highest weight (50%), then the following three decreasing weights (25%, 15%, and 10%). The equal weightage choice (25% for each challenge) offered a fair weight distribution, addressing circumstances when decision-makers might prefer a consistent assessment across difficulties. Table 3.7 shows the details of the default weightage distribution. The tool's functionality was flexible and applicable to various decision circumstances, allowed users to customize weights according to their specific project context and preferences. This promoted effective decision-making in LID practices.

Table 3.7 Weightage based on priority selection.

Priority Options	Weightage
One	0.5
Two	0.25
Three	0.15
Four	0.1
Equal	0.25

Benefit Scoring: Benefit scoring played a significant role in the decision-making process for evaluating LID scenarios. The scoring involved several steps to objectively assess selected LID strategies based on predetermined criteria and priorities. In benefit scoring, each challenge was linked to a corresponding criterion for scoring, as shown in Figure 7.

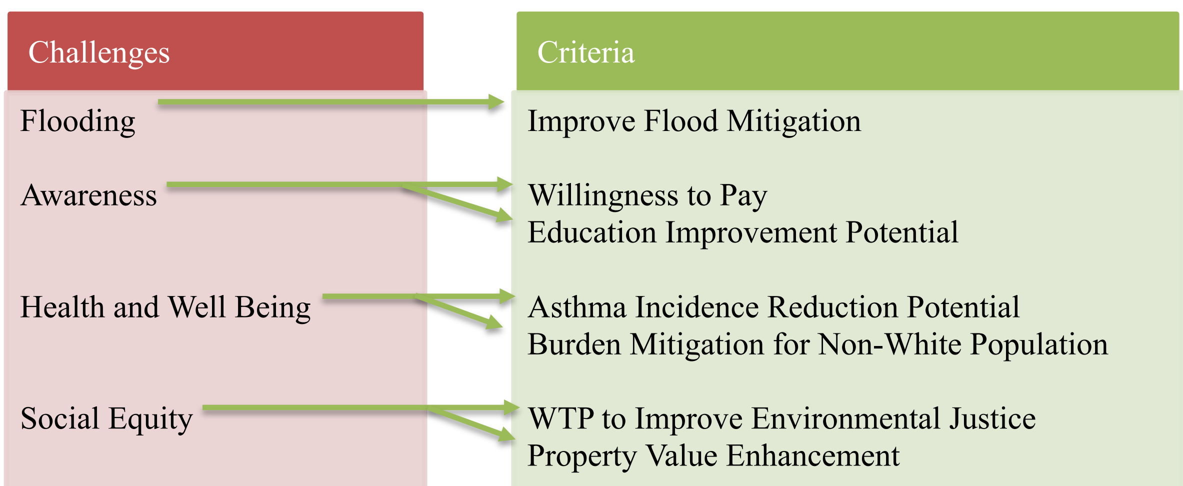


Figure 7 Exploring criteria linked challenges

The weightage was evenly divided when two criteria were linked to the same challenge. Each criterion's value was compared to median or maximum and minimum values, and "1" and "2" points are assigned accordingly. These scores were then weighted according to the predefined priorities and challenges, reflecting their relative importance shown in Equation 7. This results in an overall score for selected LID strategy, calculated by aggregating the weighted scores. To perform the weighted average, the following formula was utilized (Croeser et al., 2021):

Equation 7

$$O(LID_i) = \sum_{k=1}^{n} B_k\,(LID_i) \times w(C_k)$$

$O(LID_i)$represents the Overall Score for LID, $B_k(LID_i)$ signifies the benefit score for the $_{th}$ criterion of i_{th} option, and (C_k) stands for weightage for the k_{th} criteria.

The scoring equation in the tool utilized is structured as follows:

[IF (Selected value < minimum value of counties, "0", "1") * IF (Selected value > median/maximum value of counties, "2")]

The overall value for LID $_i$ is the product of the weighted average of the scores for each of the k criteria, each of which has a base value of ten. The overall score effectively indicated the sum of the weighted criteria scores for benefit.

3.3.3 Scenario Analysis

Scenario 1 was considered in Fox Hollow on James Island, SC as shown in Figure 8. The project used a network of constructed stormwater wetlands integrated with the adjacent natural wetlands to ensure effective stormwater control. A bioswale system was introduced, and conventional stormwater ponds were replaced with Bioretention cells (Ellis et al., 2014). This study considered only swales with a footprint of 0.44 Acres, or 19166.4 SF. Fox Hollow was chosen as scenario 1, as the project had received extensive acclaim from media outlets such as Post & Courier and South Carolina Public Radio, which emphasized its positive impact on the community. This recognition confirmed the project's social and economic significance. Although swales can be expensive initially, evaluating their benefits may outweigh their long-term costs.

Figure 8 Map showing scenario 1 in James Island, South Carolina

Scenario 2 was set in Charlotte, North Carolina, as shown in Figure 9, where the Westfield Level Spreader project utilized LID strategies to control water flow. The project consisted of a vegetated swale and a 150-foot-long grassed filter strip to treat stormwater (Hathaway & Hunt, 2007). For this study, only the grass strip was considered and categorized as roadside vegetation. The grassed filter strip covered an area of approximately 2000 square feet with a minimum width of 20 feet. During heavy rainfall, the initial inch of water was directed to a level spreader. Then, the water was released onto a 150-foot grassed filter strip, and it filtered and collected the water in a swale. The purpose of scenario 2 was to analyse the geographic variations in the benefits and costs of vegetation and assess the potential advantages with low initial costs.

Figure 9 Map illustrating scenario 2 in Charlotte, North Carolina

CHAPTER 4: DECISION SUPPORT TOOL (DST)

This section expands further into the Decision Support Tool (DST), highlighting key features and individual spreadsheet tabs with details on how the DST works and defining how each element contributes to the evaluation process. From scenario comparisons to location details, LID BMP specifics, and project objectives, convey how to use DST in detail.

4.1 Key Features

The MS Excel-based decision support tool (refer to Appendix B to access a link to the decision support tool) aims to go beyond analyzing numbers to transform social and economic metrics into actionable insights for decision-making. This tool required user input cells for calculations, with most metric calculations relying on geography. Therefore, accurate county and census tract geo ID details were necessary. This tool used several linked sheets with formulas to look up data and calculate metrics with a unified framework, as shown in Figure 10. This unified framework integrated the socio-economic framework with the decision framework through benefit scoring.

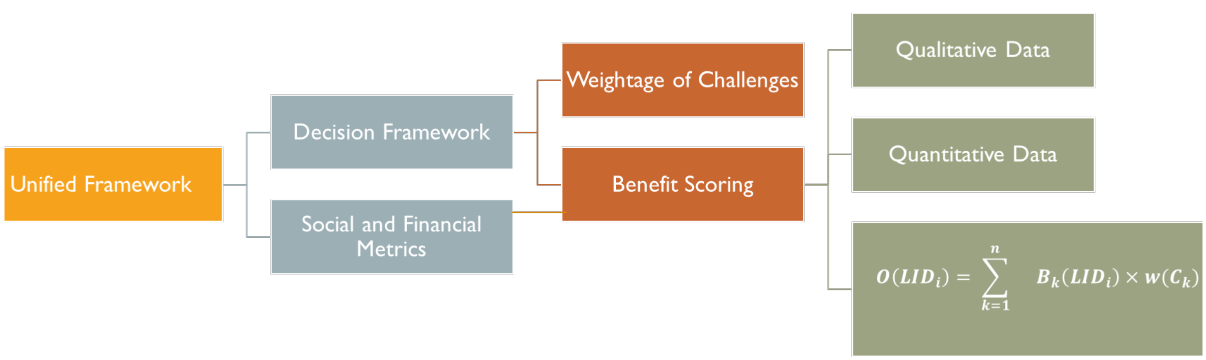


Figure 10 Unified framework showing benefits scoring and interdependency on metrics

Benefits scoring integration and interdependency on metrics combine to establish a mutually beneficial relationship where social and financial metrics work together to aid decision-making. This scoring was intended to show users the likelihood of the selected LID in mitigating their priority challenges. Apart from benefit scoring, the tools generate costs and potential benefits. This tool was tested with hand calculations and refer to Appendix A, which contains verification documentation. Two previously implemented projects in North Carolina and South Carolina with similar climate zones were used as scenarios to evaluate this decision support tool's potential.

4.2 Overview of Sheets in the Decision Support Tool

A. Introduction

The purpose of this sheet is to provide information and usage tips about the tool, as shown in Figure 11. The tool is designed to help users compare construction and maintenance costs, property value enhancement, and more to identify the benefits of each LID scenario. Users can easily navigate the tool using dropdown lists and custom values for personalized analyses. The tool's effectiveness relies on using Microsoft Excel 365, and detailed instructions, priority options, and weightage customization further enhanced the user experience.

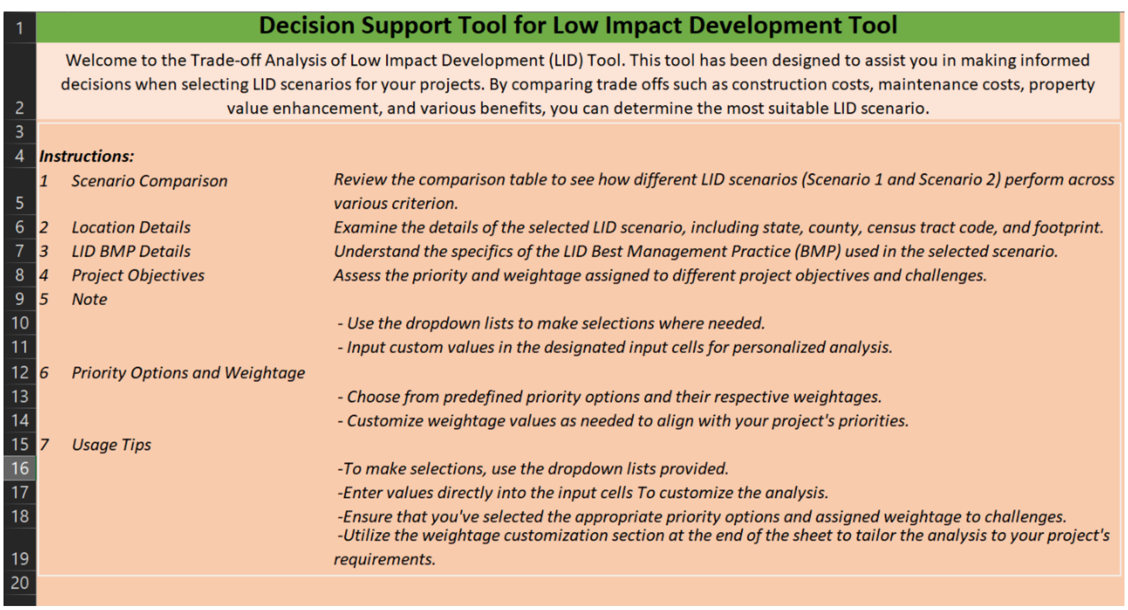


Figure 11 Introduction sheet in decision support tool

B. S1 & S2 Output

This sheet enables a comparison between scenario 1 and scenario 2, as shown in Figure 12. It presents key metrics and their total costs and benefits. It also shows overall scores for both scenarios, respectively, to reflect the efficacy of each scenario in meeting project objectives. This sheet serves as a quick reference for users, offering a snapshot of the economic and social implications of the two LID options. This sheet is intended to help users to identify the trade-offs between economic investments and social benefits. This approach promotes dynamic, adaptive, and reward-driven decision-making to optimize social and financial outcomes in sustainable urban development.

	A	B	C	D
1	**Trade off Analysis of Low Impact Development**			
2			**Scenario 1**	**Scenario 2**
3	*Location*		*South Carolina*	*North Carolina*
4			*Charleston*	*Mecklenburg*
5	LID Footprint		*19166.4*	*2000*
6	**Selected LID**		**Roadside Swale**	**Roadside Vegetation**
7	**Overall Score / 10**		**6.9**	**3.9**
8	Construction Costs ($)	$	707,816	$ 1,400
9	Annual Maintenance Costs ($/yr)	$	35,267	$ 240
10	**Total Costs**	**$**	**743,083**	**$ 1,640**
11	Enhanced Property Value Per Household ($)	$	3,754	$ 2,868
12	Savings from Improved Flood Mitigation ($/ FE)	$	22,971	$ 685
13	Savings from Avoided Carbon Emissions ($/yr)	$	384	$ 20
14	Annual WTP for Recreational Areas ($/yr)	$	37,455	$ 21,093
15	Annual WTP (Water Quality & Aquatic Habitat Improvements) ($/yr)	$	27,060	$ 16,710
16	**Total Benefits**	**$**	**91,624**	**$ 41,376**
17				
18				
19				
20				

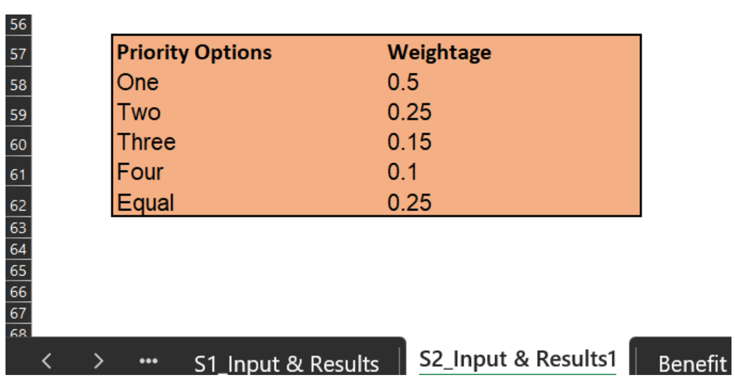
Introduction | S1 & S2 Output | S1_Input & Results | S2_Input & Results1 | Benefit C...

Figure 12 This sheet presents overview of outcomes of scenarios.

C. S1_ Input & Results and S2_ Input & Results

On the bottom left corner of these sheets, users can customize the priority weights according to their requirements from each scenario respectively as shown in Figure 13. These sheets allow users to enter inputs on the left, showing LID options and location details as specific as county and census tract geo IDs, for scenarios 1 and 2 as shown in Figure 14 & 15. On the right are metric outcomes with costs and potential benefits of each scenario. These sheets provide various options for selection, challenges, and a priority section that allow users to assign weights. This makes it a valuable tool for users to align their project objectives. Additionally, some definitions for user inputs are listed below:

- State & County – States are large geographical areas, Counties are smaller subdivisions of a state*, as defined by the U.S. Census Bureau.*
- Census Tract GEO ID – *A unique identifier used in demographic data collection and reporting for specific geographic areas, as defined by the U.S. Census Bureau.*
- LID BMP Type – refers to the variation of LID options.
- Footprint – denotes the space occupied by the LID installation.
- Project Objectives – *Key challenges were identified for the tool based on their capacity to improve:*
    - *Flooding: Examining the potential risk associated with excessive water.*
    - *Awareness: Assessing the level of community's understanding towards LID.*
    - *Social Equity: Analyzing the impartial distribution of LID in the community.*
    - *Public Health and Wellbeing: Evaluating the health conditions within the community.*



Priority Options	Weightage
One	0.5
Two	0.25
Three	0.15
Four	0.1
Equal	0.25

Figure 13 Customizable weightage at the left bottom of input sheets

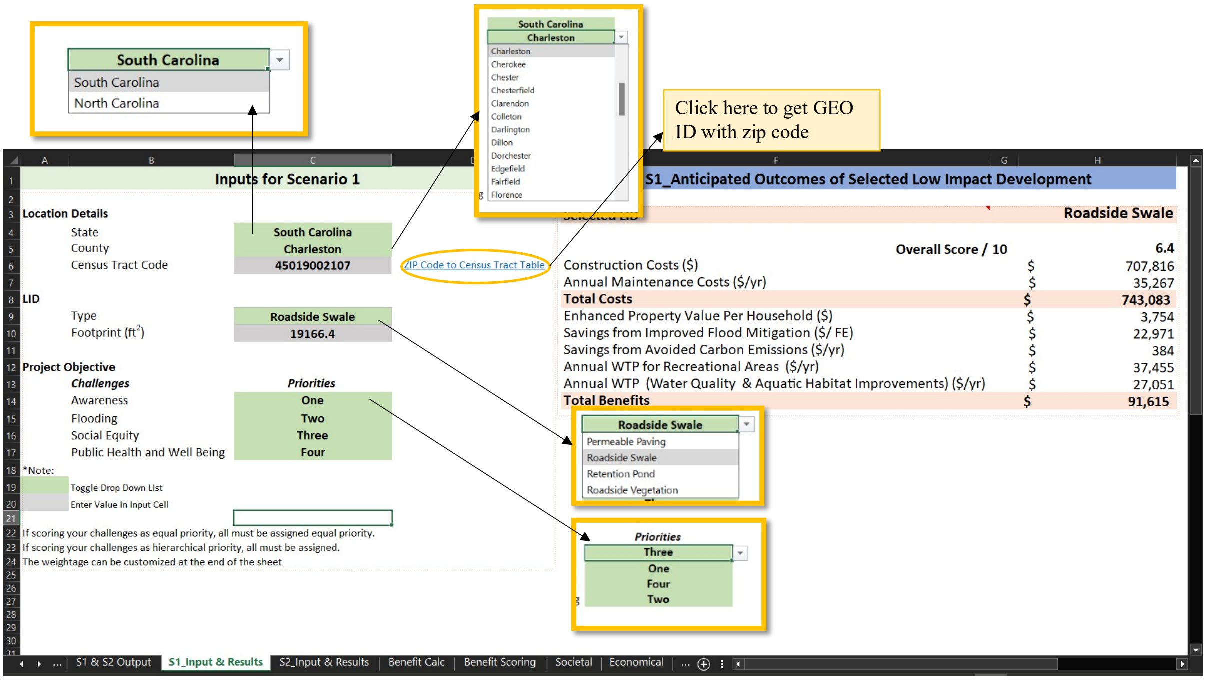


Figure 14 User inputs for scenario 1 on the left and depicts outcomes on the right.

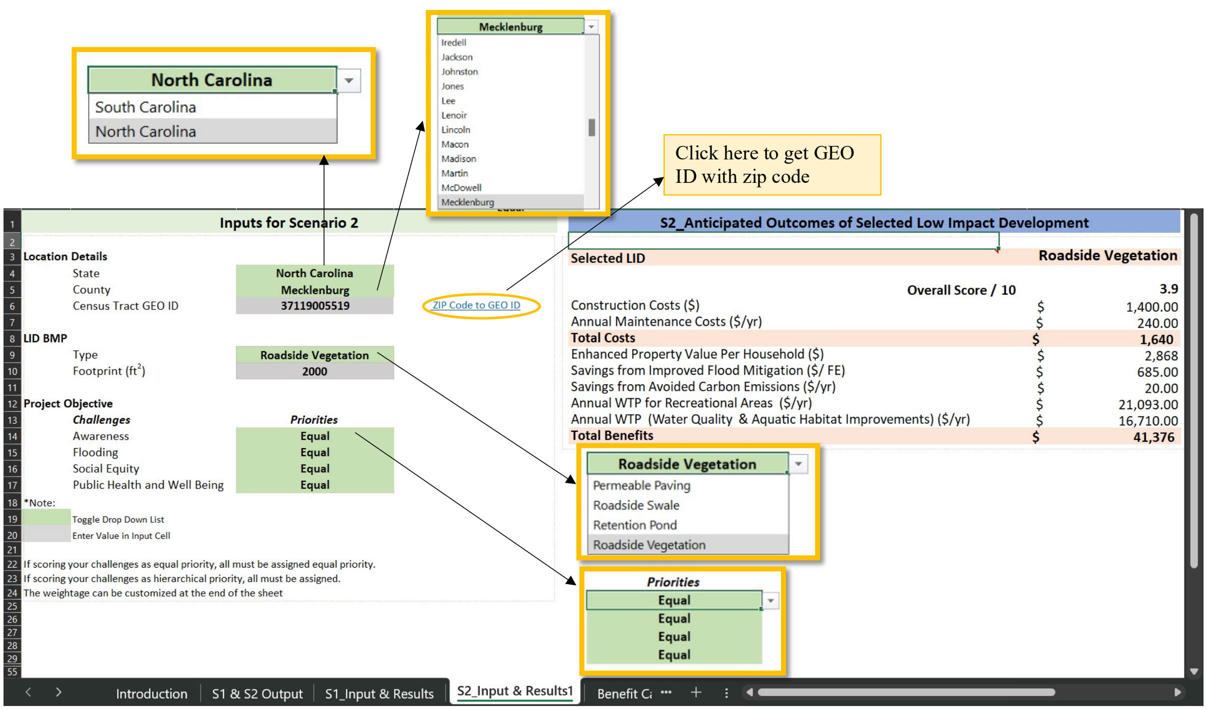


Figure 15 User inputs for scenario 2 on the left and depicts outcomes on the right.

D. Benefit Calc

This sheet is created for viewing only and should not be edited. It presents the overall benefits social and economic aspects of both scenarios, both scenarios as shown in Figure 16. This sheet is provided in case of errors or troubleshooting to assess if errors appear on this sheet quickly appear on this sheet. This allows the user to swiftly spot problems caused by back-end computation errors.

Overview of Anticipated Benefits and Costs			
	Benefit Score of Low Impact Development	Scenario 1	Scenario 2
		Roadside Swale	Roadside Vegetation
	Overall Score	6.4	3.9
Social	Annual WTP (Water Quality & Aquatic Habitat Improvements) ($/yr)	$ 27,051	$ 16,710
	Annual WTP for Recreational Areas ($/yr)	$ 37,455	$ 21,093
	Savings from Avoided Carbon Emissions ($/yr)	$ 384	$ 20
Economic	Savings from Improved Flood Mitigation ($/ FE)	$ 22,971	$ 685
	Construction Costs ($)	$ 707,816	$ 1,400
	Annual Maintenance Costs ($/yr)	$ 35,267	$ 240
	Total GI Cost ($)	$ 743,082	$ 1,640
	Enhanced Property Value Per Household ($)	$ 3,754	$ 2,868

****Please note that this sheet is for viewing only and should not be edited**

Troubleshooting:

If the erorr appears here, then error occurred in the back end sheet

Figure 16 Benefit calc sheet showing overall outcomes and notes for troubleshooting.

E. Benefit Scoring

This sheet is intended to calculate the likelihood of accomplishing project objectives based on the user assigned priorities for addressing challenges through LID. The points are then calculated for the identified criteria as unweighted scores. The weightages are then applied to each scenario to produce the weighted benefit ratings across key social and economic criteria. This sheet serves as a reference for the customizable priorities from input sheets at the bottom and provides a lookup for weightages on the top assigned to challenges in the benefit scoring process for both scenarios, S1 and S2, as shown in Figure 17. This also depicts the breakdown of social and economic scores.

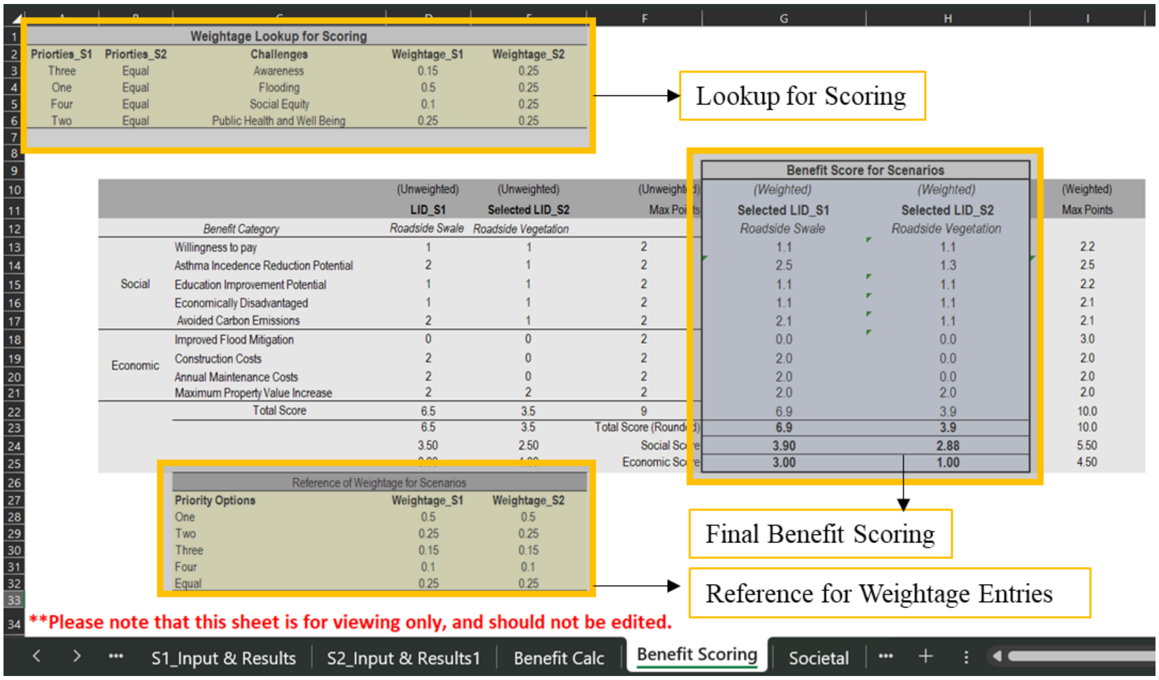
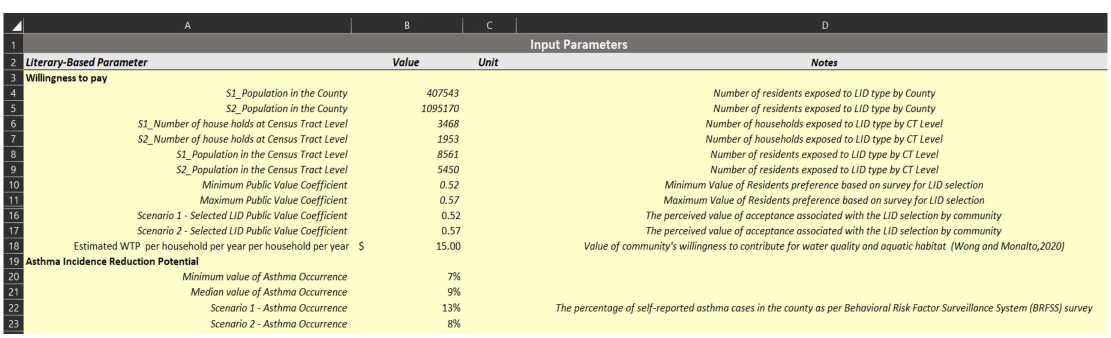


Figure 17 Benefit scoring sheet showing weighted and unweighted scores for scenarios.

F. Societal and Economical

These sheets display literary inputs drawn from data tables, user inputs used for calculations, equations involved, and respective metric results. These sheets are viewed only and should be edited in case of resolving errors only. Social and economic metrics with literary inputs, calculations and results are shown in Figures 18 &19. and Figures 20&21 respectively.



Input Parameters			
Literary-Based Parameter	***Value***	***Unit***	***Notes***
Willingness to pay			
S1_Population in the County	*407543*		*Number of residents exposed to LID type by County*
S2_Population in the County	*1095170*		*Number of residents exposed to LID type by County*
S1_Number of house holds at Census Tract Level	*3468*		*Number of households exposed to LID type by CT Level*
S2_Number of house holds at Census Tract Level	*1953*		*Number of households exposed to LID type by CT Level*
S1_Population in the Census Tract Level	*8561*		*Number of residents exposed to LID type by CT Level*
S2_Population in the Census Tract Level	*5450*		*Number of residents exposed to LID type by CT Level*
Minimum Public Value Coefficient	*0.52*		*Minimum Value of Residents preference based on survey for LID selection*
Maximum Public Value Coefficient	*0.57*		*Maximum Value of Residents preference based on survey for LID selection*
Scenario 1 - Selected LID Public Value Coefficient	0.52		*The perceived value of acceptance associated with the LID selection by community*
Scenario 2 - Selected LID Public Value Coefficient	0.57		*The perceived value of acceptance associated with the LID selection by community*
Estimated WTP per household per year per household per year	$ 15.00		*Value of community's willingness to contribute for water quality and aquatic habitat (Wong and Monalto,2020)*
Asthma Incidence Reduction Potential			
Minimum value of Asthma Occurrence	7%		
Median value of Asthma Occurrence	9%		
Scenario 1 - Asthma Occurrence	13%		*The percentage of self-reported asthma cases in the county as per Behavioral Risk Factor Surveillance System (BRFSS) survey*
Scenario 2 - Asthma Occurrence	8%		

Figure 18 Societal sheet displaying literary based inputs of each metric

	A	B		C	D
40	**Calculations**				
41	***Parameter***		***Value***	***Unit***	***Notes***
42	**Willingness to pay (Social Acceptance)**				
43	*S1_Minimum Social Acceptance Value*	*$*	*27,051.00*		
44	*S2_Minimum Social Acceptance Value*	*$*	*15,234.00*		
45	*S1_Maximum Social Acceptance Value*	*$*	*29,652.00*		
46	*S2_Maximum Social Acceptance Value*	*$*	*46,598.00*		
47	*S1_Selected LID Social acceptance*		1804		
52	*S2_Selected LID Social acceptance*		1114		
53	*S1_Selected LID WTP*	$	27,060.00		
58	*S2_Selected LID WTP*	$	16,710.00		$WTP_{wq} = Pop \times PVC \times C_A$
59	**Asthma Incidence Reduction Potential**				
60	*Minimum value of Asthma Occurrence*		7%		*The Minimum percentage of self-reported asthma cases in the county as per Behavioral Risk Factor Surveillance System (BRFSS) survey*
61	*Median value of Asthma Occurrence*		9%		*The Median percentage of self-reported asthma cases in the county as per Behavioral Risk Factor Surveillance System (BRFSS) survey*
62	*S1_Asthma Incidence at selected loction*		13%		
63	*S2_Asthma Incidence at Selected Location*		8%		
64					
65	**Education Improvement Potential**				
66	*S1_Education Advancement Potential at selected location*		341		*The prospect of strengthening future education by taking into account the proportion of individuals under 18 as per 2020 5-year intervals data by the American Community Survey data*
67	*S2_Education Advancement Potential at selected location*		0.32		
68					
69	**Annual WTP for Recreational Benefits**				
70	*S1_WTP for Recreational Areas*	$	37,454.40		$WTP_R = Pop \times Cost\ for\ Recreational\ Benefits\ per\ SF$
71	*S2_WTP for Recreational Areas*	$	21,092.40		
72	**Savings from Avoided Carbon Emissions**				
73	*S1_ Annual Social Cost of Carbon Emissions per year*	$	383.33		$Savings\ from\ Avoided\ Carbon\ Emissions = (LID\ Footprint) \times \left(\frac{CO_2}{Emissions}\right)$
74	*S2_ Annual Social Cost of Carbon Emissions per year*	$	20.00		
75	**Results**				
76	**Parameter**		**Value**	**Units**	***Notes***
77	***Willingness to pay***				
78	*S1_Selected LID WTP*	$	27,060		*The community's willingness to pay for acquatic improvements*
79	*S2_Selected LID WTP*	$	16,710.00		

S1_Input & Results | S2_Input & Results1 | Benefit Calc | Benefit Scoring | Societal

Figure 19 Societal sheet displaying calculations and results of each metric.

A	B		C	D–H
Input Parameters				
iterary-Based Parameter		***Value***	***Unit***	***Notes***
osts				
ID Costs				Costs associated with construction and maintenance of green infrastructure as per CNT Calculator
Baseline Minimum LID Construction Unit cost (state default value)	$	0.70	$/SF	
Baseline Median LID Construction Unit cost (state default value)	$	22.81	$/SF	
Baseline Minimum Maintenance Unit Cost (state default value)	$	0.04	$/SF/yr	
Baseline Median Maintenance Unit Cost (state default value)	$	0.98	$/SF/yr	
Scenario 1 - Selected LID Construction Cost (state default value)		36.93	$/SF	
Scenario 1 - Selected LID Annual Maintenance Cost (state default value)		1.84	$/SF/yr	
Construction Units (CU)		1		
Maintenance Units (MU)		1		
Scenario 2 - Selected LID Construction Cost (state default value)		0.7	$/SF	
Scenario 2 - Selected LID Annual Maintenance Cost (state default value)		0.12	$/SF/yr	
enefits				
ncrease in property values				

Figure 20 Economical sheet displaying literary inputs of each metric.

	A	B		C	D–H
41	**Calculations**				
42	***Parameter***		***Value***	***Unit***	
43	**LID Costs**				
44	*Baseline Minimum LID Construction Cost*	$	13,416.48		$Construction\ Costs = Unit\ Cost\ per\ SF * Footprint\ of\ the\ BMP * One\ unit\ of\ BMP$
45	*Baseline Median LID Construction Cost*	$	437,185.58		$Maintenance\ Costs = Unit\ Cost\ per\ SF * Footprint\ of\ the\ BMP * One\ unit\ of\ BMP$
46	*Baseline Minimum LID Annual Maintenance Costs*	$	766.66		$Total\ cost\ of\ GI = (Construction\ Costs) + (Maintenance\ Costs)$
47	*Baseline Median LID Annual Maintenance Costs*	$	18,783.07		
48	*Baseline Minimum Total LID Cost Estimate (pre defined)*	$	14,183.14		
49	*Baseline Median Total LID Cost Estimate (pre defined)*	$	455,968.66		
50	*Scenario 1 Selected LID Construction Costs (pre defined)*	$	707,815		
51	*Scenario 1 Selected LID Annual Maintenance Costs (pre defined)*	$	35,266		
52	*Scenario 1 Selected LID Total cost estimate (pre defined)*	$	743,081		
53	*Scenario 2 Selected LID Construction Costs (pre defined)*	$	1,400		
54	*Scenario 2 Selected LID Annual Maintenance Costs (pre defined)*	$	240		
55	*Scenario 2 Selected LID Total cost estimate (pre defined)*	$	1,640		
56	**Increase in Property Values**				
57	*Baseline Minimum Property Value by County*	$	1,251.28		$Increase\ in\ Property\ Value = Median\ Property\ Value\ of\ county * BMP\ Property\ Value\ Increase\ \%$
58	*Baseline Median Property Value by County*	$	2,502.55		
59	*Scenario 1 - Maximum Property Value Increase for Selected LID*	$	3,754		
64	*Scenario 2 - Maximum Property Value Increase for Selected LID*	$	2,868		
65	**Savings from Improved Flood Mitigation**				
66	*Baseline Minimum Avoided costs on Future Losses*	$	74,403		
67	*Baseline Median Avoided costs on Future Losses*	$	659,325		$Improved\ Flood\ Mitigation = LID\ Footprint \times Flood\ risk \times 7 \times (LID\ Intial\ Cost)$
68	*Scenario 1- Avoided costs on Future Losses for Selected LID*	$	22,971		
73	*Scenario 2 - Avoided costs on Future Losses for Selected LID*	$	684		
74	**Results**				
75	Parameter		Value	Units	
76	*Costs*				
77	**LID Costs**				
78	*Scenario 1 Selected LID Construction Costs (pre defined)*	$	707,815.15		
79	*Scenario 1 Selected LID Annual Maintenance Costs (pre defined)*	$	35,266.18		

Benefit Calc | Benefit Scoring | Societal | Economical | Parameters | CT ID_ACS_2(

Figure 21 Economical sheet displaying calculations and results of each metric.

G. Parameters

This sheet comprises of county-wise and finance data supplementing lookup references shown in Figure 23 for metric calculations. Cost data relating to each LID type per square foot per year is used to calculate costs and benefits, shown in Figure 22. This sheet should only be edited if necessary to update the county level socio economic data and financial cost data.

**Please note that this sheet is for viewing only, and should not be edited.

NC County	NC Property Value ($)	NC Asthma (%)	NC County Total Population	RISK_SCORE (%)
Alamance	$ 273,592.00	7.50%	166144	74%
Alexander	$ 241,330.00	7.80%	37271	35%
Alleghany	$ 253,818.00	13.10%	11085	**8%**
Anson		7.00%	24430	64%
Ashe	$ 296,974.00	13.10%	27009	26%
Avery	$ 253,075.00	8.90%	17510	47%
Beaufort	$ 221,095.00	8.50%	47160	94%
Bertie	$ 123,044.00	8.50%	19081	82%
Bladen	$ 141,746.00	7.60%	33209	91%
Brunswick	$ 417,943.00	7.60%	137303	97%
Buncombe	$ 445,378.00	8.90%	259576	81%
Burke	$ 228,024.00	8.90%	90148	65%
Cabarrus	$ 385,914.00	7.80%	211605	80%
Caldwell	$ 207,956.00	8.90%	82056	61%
Camden	$ 380,673.00	8.50%	10654	49%
Carteret	$ 432,268.00	8.50%	69301	97%
Caswell	$ 172,864.00	7.50%	22619	25%

	Property Increase Rate (%) (CNT,2010)	WTP	Construction Estimate (CNT,2010)	Maintenance Estimate (CNT,2010)	Value of Avoided Carbon Emissions (FEMA,2022)	Drought Risk Reduction (FEMA,2022)	Stormwater Volume and Quality (FEMA,2022)
LID Type	($/SF/Yr)	PVC	CE ($/SF)	ME	($/SF/Yr)	($/SF/Yr)	($/SF/Yr)
Permeable Paving	0.23%	0.52	8.69	0.04	0.003	0.13	0.51
Roadside Swale	0.69%	0.52	36.93	1.84	0.02	0.52	1.8
Retention Pond	0.23%	0.52	36.93	1.84	0.02	0.52	1.8
Roadside Vegetation	0.69%	0.57	0.7	0.12	0.01	5.53	0.09
Selected Scenario 1	0.69%	0.52	36.93	1.84	0.02	0.52	1.8
Selected Scenario 2	0.69%	0.57	0.7	0.12	0.01	5.53	0.09
Baseline Minimum	0.23%	0.52	$ 0.70	0.04	0.003	0.13	0.09
Baseline Maximum	0.46%	0.57	$ 22.81	0.98	0.015	0.52	1.155
		maximum					

Financial cost estimates are based on a net present value calculation which assumes a **3.1**% discount rate over a **30** year life-cycle for all green and conventional investments.

FEMA

Benefit Scoring | Societal | Economical | Parameters | CT ID_ACS_2020

Figure 22 Demographic data, risk score, financial cost data to estimate costs and benefits.

State List	SC County List	NC County List	S1_Selection	S2_Selection
	South Carolina	**North Carolina**	Abbeville	Alamance
North Carolina	Abbeville	Alamance	Aiken	Alexander
South Carolina	Aiken	Alexander	Allendale	Alleghany
	Allendale	Alleghany	Anderson	Anson
	Anderson	Anson	Bamberg	Ashe
	Bamberg	Ashe	Barnwell	Avery
	Barnwell	Avery	Beaufort	Beaufort
	Beaufort	Beaufort	Berkeley	Bertie
	Berkeley	Bertie	Calhoun	Bladen
	Calhoun	Bladen	Charleston	Brunswick
	Charleston	Brunswick	Cherokee	Buncombe
	Cherokee	Buncombe	Chester	Burke
	Chester	Burke	Chesterfield	Cabarrus
	Chesterfield	Cabarrus	Clarendon	Caldwell
	Clarendon	Caldwell	Colleton	Camden
	Colleton	Camden	Darlington	Carteret
	Darlington	Carteret	Dillon	Caswell
	Dillon	Caswell	Dorchester	Catawba
	Dorchester	Catawba	Edgefield	Chatham
	Edgefield	Chatham	Fairfield	Cherokee
	Fairfield	Cherokee	Florence	Chowan
	Florence	Chowan	Georgetown	Clay

Figure 23 This is a lookup reference list for the dropdown menu of counties in user input.

H. CT ID_ACS_2020

This sheet comprises of census tract-level data about demographic data in North Carolina and South Carolina required for metric calculations, as shown in Figure 24. Please note that this document contains crucial information and should only be edited if necessary to update this data. Any changes made to this document should be carefully reviewed to ensure that the data remains accurate.

**Please note that this sheet is for viewing only, and should not be edited.

County Name	GEOID	Census Tract Households of Population Under 18	CT Total Households Below Poverty Level	CT Non-White & Hispanic or Latino Population	CT Total Households	CT Total Population	Census Tract % of Population Under 18	CT % Non-White & Hispanic or Latino	Census Tract ID
NC									
Alamance County	37001020100	625.68	416	1375	1842	4048	19.24%	33.97%	20100
Alamance County	37001020200	940.28	553	2809	1349	4030	32.85%	69.70%	20200
Alamance County	37001020301	950.71	366	2572	1422	3847	20.56%	66.86%	20301
Alamance County	37001020302	973.32	192	2958	1228	3732	30.09%	79.26%	20302
Alamance County	37001020400	2037.08	679	5354	2526	6639	29.58%	80.64%	20400
Alamance County	37001020501	328.10	171	966	1380	4063	23.23%	23.78%	20501
Alamance County	37001020502	1102.07	463	3127	1476	4188	33.95%	74.67%	20502
Alamance County	37001020601	127.44	38	289	1431	3245	18.43%	8.91%	20601
Alamance County	37001020602	158.20	64	341	1299	2800	19.82%	12.18%	20602
Alamance County	37001020701	596.27	243	1316	2415	5330	12.18%	24.69%	20701
Alamance County	37001020702	1093.73	446	2269	2535	5259	22.32%	43.15%	20702
Alamance County	37001020801	280.40	39	678	689	1666	21.49%	40.70%	20801
Alamance County	37001020802	1813.55	587	4584	2316	5854	21.73%	78.31%	20802
Alamance County	37001020901	535.87	110	1154	1531	3297	20.11%	35.00%	20901

Benefit Scoring | Societal | Economical | Parameters | CT ID_ACS_2020

Figure 24 CT_ID_ACS_2020 sheet display, census tract level demographic data.

CHAPTER 5: RESULTS FROM DECISION SUPPORT TOOL SCENARIOS

This section presents the potential outcomes of two selected scenarios for the fox hollow project in South Carolina and the west field spreader in North Carolina. By drawing comparisons and detailing cost-benefit trade-offs, one can better understand the potential impacts of these projects generated by the DST.

5.1 Scenario 1 Results

Scenario 1 featured the establishment of a swale at Fox Hollow on James Island, South Carolina, which was planned in 2012 by the combined efforts of New Leaf Builders and Robinson. Design Engineers. As listed in Table 5.1 that the project's objectives were focused on mitigating flooding while preserving the natural ecosystem of the land with minimal alterations. So, hierarchical weightage given to flooding as highest priority assigned to mitigate the challenge..

Table 5.1 User Inputs for scenario 1 - James Island_RS Project

Scenario 1: Fox Hollow Low Impact Development	
Location Details:	
County	Charleston County
City	James Island, SC
Census Tract Code	45019002107
LID BMP Details:	
BMP Type	Roadside Swale
Footprint (ft2)	0.44 Acre or 19166.4 SF
Project Objective	Minimize Flooding
Land Use Description	Residential
Engineer	Robinson Design Engineers
Builder	New Leaf Builders

Scenario 1 involves the implementation of a Roadside Swale at James Island, offers an evaluation of costs and potential benefits, as shown in Figure 25. According to the outcomes, the expected upfront expenses come to roughly $707,816 and the annual maintenance costs come to $35,267. The swales have the potential to reduce runoff might create savings from the next flood event is $22,971/year. In addition, swales commitment to fostering ecological balance by minimizing carbon emissions has been highlighted by the inclusion of potential savings from averted carbon dioxide emissions ($384/year).

The community's preference for enhanced recreational areas and ecological improvements can be seen in the annual willingness-to-pay (WTP) for recreational areas and the quality of water and aquatic habitat enhancements, which amount to $37,455/year and $27,051/year, respectively. This focus on community preferences underlines the swale's alignment with local demands and this scenario's total potential benefits surpass $91,615 overall, proving its significant positive impact. However, the roadside swale's total score indicates that it may mitigate flooding and meet project objectives.

S1_Anticipated Outcomes of Selected Low Impact Development		
Selected LID		**Roadside Swale**
Overall Score / 10		**6.4**
Construction Costs ($)	$	707,816.00
Annual Maintenance Costs ($/yr)	$	35,267.00
Total Costs	**$**	**743,083**
Enhanced Property Value Per Household ($)	$	3,754
Savings from Improved Flood Mitigation ($/ FE)	$	22,971.00
Savings from Avoided Carbon Emissions ($/yr)	$	384.00
Annual WTP for Recreational Areas ($/yr)	$	37,455.00
Annual WTP (Water Quality & Aquatic Habitat Improvements) ($/yr)	$	27,051.00
Total Benefits	**$**	**91,615**

Figure 25 Outcome for scenario 1 at James Island

5.2 Scenario 2 Results

The Westfield Level Spreader situated adjacent to Little Sugar Creek in Charlotte, NC, depicted in Figure 26, serves as a crucial stormwater management feature for the Westfield neighborhood in Charlotte. Considering grass strip installation of 2000SF with equal weightage on priorities for challenges as shown in Table 5.2.

Table 5.2 User Inputs for scenario 2 - Charlotte_RV Project

Scenario 2: Westfield Level Spreader	
Location Details:	
County	Mecklenburg
City	Charlotte, NC 28209, US
Census Tract Code	37119005519
LID BMP Details:	
Implemented BMP Type	Roadside Vegetation
Footprint (ft^2)	2000 SF
Project Objective	Equal Weightage
Land Use Description	Medium Density Residential

In scenario 2's roadside vegetation at Charlotte, is evaluated with equal weightage of the criteria and outcome is shown in Figure 26 .With low intial costs of $1400 and $240 per maintenance costs per year, implementing this LID may result in potential cost savings of $685 per future flood event. Additionally, the savings from avoided carbon emissions ($20/year) show a negligible improvement. The community's willingness to pay $21,093 annually for recreational areas and $16,710 for water quality and habitat improvements annually. Overall, the scenario's total potential benefits come to $41,376, highlighting the roadside vegetation in scenario 2 as a potential source of profit with low initial costs. Despite the presence of visible 20 fold profit on benefits, the score indicates a potential shortfall in achieveing project objective.

S2_Anticipated Outcomes of Selected Low Impact Development		
Selected LID		**Roadside Vegetation**
Overall Score / 10		**3.9**
Construction Costs ($)	$	1,400.00
Annual Maintenance Costs ($/yr)	$	240.00
Total Costs	**$**	**1,640**
Enhanced Property Value Per Household ($)	$	2,868
Savings from Improved Flood Mitigation ($/ FE)	$	685.00
Savings from Avoided Carbon Emissions ($/yr)	$	20.00
Annual WTP for Recreational Areas ($/yr)	$	21,093.00
Annual WTP (Water Quality & Aquatic Habitat Improvements) ($/yr)	$	16,710.00
Total Benefits	**$**	**41,376**

Figure 26 Outcome for scenario 2 at Charlotte

5.3 Cost Benefit Trade-offs in Scenario Analysis

In these scenarios, the benefits perceived are closely tied to location, footprint, and the type of chosen. When comparing scenarios 1 and 2, it was seen that the roadside vegetation project costs $1,400 to construct, whereas the roadside swale project costs approximately $707,816 (as shown in Figure 27). Additionally, the swale carries higher maintenance costs at $35,267, compared to the vegetation's $240. The swale enhances property value by $3,754, while the vegetation shown improvement by $2,868 (as shown in Figure 28). Moreover, the swale's potential cost savings from flood mitigation, approximately $22,971, significantly outweigh the vegetation's savings of about $685 (as shown in Figure 28). This suggests that there may be a direct correlation between higher investments and higher returns.

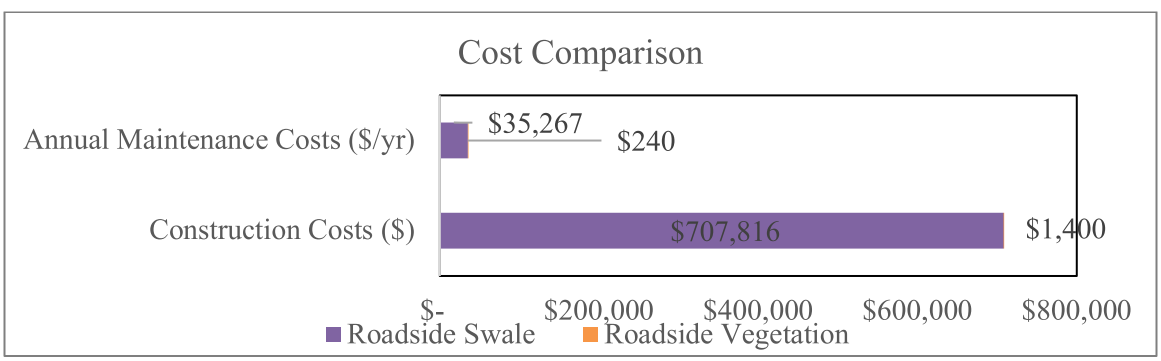


Figure 27 The cost comparison between scenarios

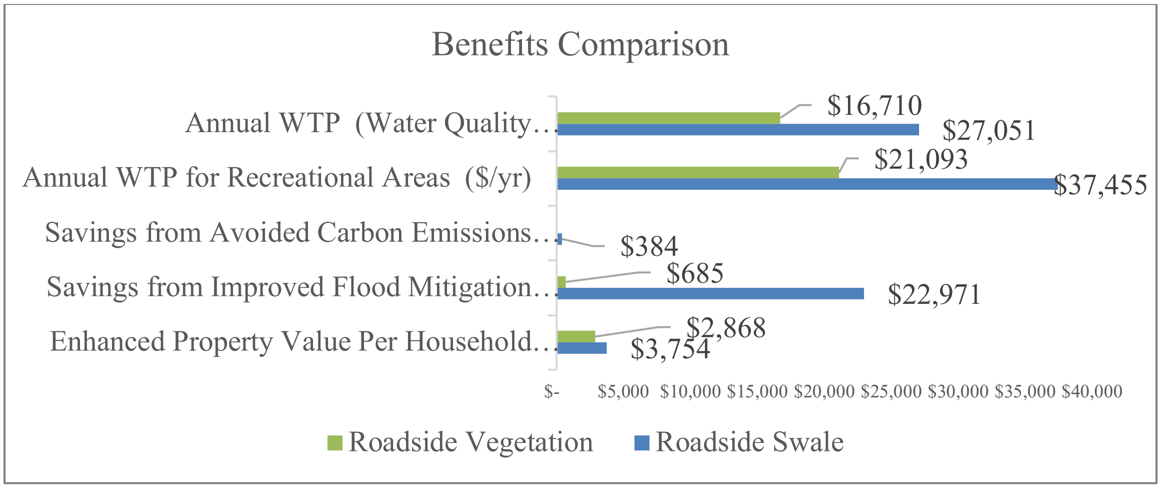


Figure 28 Potential benefits comparison between scenarios

CHAPTER 6: CONCLUSION

Despite the pressing need to quantify the social and economic benefits of LID strategies, there is currently little data available on the topic. This study aims to bring together knowledge from multiple sources and provide a comprehensive analysis of the socio-economic benefits of LID, while also enabling decision-makers to identify the rewards. By doing so, this research hoped to shed light on the short-term and long-term returns of incorporating LID in city planning. This study provides a step towards unlocking the full potential of LID in creating sustainable, resilient, and equitable communities. This study presents a method for assessing the societal and financial advantages of implementing LID techniques. The assumptions made in this method can be adjusted according to the specific conditions of a particular location and can be utilized with change in static data relevant to other regions.

6.1 Economic & Social Impact

The study examined the potential impacts of LID strategies on society and yielded significant results. One prime example of how LID strategies can benefit society is the roadside swale, which has the potential to save $22,971 per year from the next flood event. This project effectively demonstrates that the goals of LID initiatives might be achieved. The comparative analysis of the scenario 1 in James Island and scenario 2 in Charlotte highlights the different impacts of LIDs.

Although there is a strong correlation between location, LID type, and footprint with the benefits seen in these scenarios, there is not much variation in property value improvements based on footprint variations. In scenario 2, the roadside vegetation project, which cost $1,400, resulted in a potential modest gain in property value per household of $2,868. On the other hand, the roadside swale project displayed potential to increase property value by $3,754, although it had a construction cost of nearly $707,816. Scenario 2, which gave equal weight to objectives, achieved significant benefits of $41,376 and $37,803 worth community commitment towards LID initiatives with overall score of 3.9. This suggests that this project had high potential for community acceptance. In contrast, scenario 1, which used a hierarchical approach with a higher weight on flooding, achieved a score of 6.4 and demonstrated potential savings of $22,971 from the next flood event. It's worth noting that scenario 2 also showed high returns and positive community feedback.

6.2 Challenges & Recommendations

Implementing LID measures presents a series of challenges that require a shift away from traditional practices. These challenges stem from the need for cross-disciplinary cooperation among developers, engineers, planners, and regulators to optimize ecosystem services for occupants. One of the biggest obstacles to implementing LID strategies is the lack of data linked to ecosystem services, which is essential for accurate decision-making. This scarcity makes it difficult for implementers to make informed choices. To overcome these challenges, education programs and innovations in policy and regulations are crucial. These interventions, informed by available data, streamline the implementation of LID practices.

However, challenges still arise from the decision-making process, which must consider funding mechanisms, stakeholder engagement, long-term performance, and regulatory factors. These challenges require a significant shift from traditional practices and cross-disciplinary cooperation among various stakeholders. Decision-makers can make more informed choices and effectively address challenges associated with LID strategies by leveraging data-driven approaches. This not only ensures successful and sustainable implementation of LID strategies but also fosters resilient communities.

6.3 Limitations of Research

The objective of the study was also to develop a DST that could assess the cost benefit tradeoffs of LID using pertinent data. To showcase these DST's features required making some assumptions, which could have resulted in deviations from results based on the selected location. Although geographical focus of the study was limited to North Carolina and South Carolina, certain assumptions were made regarding values and LID categories to demonstrate how the DST could compute metrics in areas where data was unavailable.

Despite the potential for LID to increase property values, there might be inconsistencies in geocoded LID data across cities regarding its long-term effects and relation to the implementation size. The national risk index utilized for evaluating flood mitigation savings and FEMA reported avoiding carbon emissions relies on assumptions derived from existing city plans and national averages. These metrics calculations may not fully capture real-world variability, necessitating cautious interpretation considering diverse local factors and climate patterns. To ensure better outcomes, users need to enter relevant prioritized challenges, state, county, census tract ID, footprint, and LID alternative. The DST developed for this study operates on Excel 365 to support its calculations. Therefore, some formulas may not be compatible with earlier versions of Excel, requiring the compatible software for accurate results.

6.4 Future Research

- It is important to investigate the link between LID and health equity, particularly in vulnerable communities, in future studies. This will help to understand the impact of LID projects on public health in these areas and provide valuable insights into the social benefits of these initiatives.

- To achieve a comprehensive understanding of the long-term advantages and challenges associated with LID, it is essential to conduct extensive, multi-decade studies. This will provide a complete view of the lasting effects of these projects and guide future implementations.
- Incorporating expert reviews for benefit scoring in future research will enhance the accuracy of evaluating low impact development initiatives, ensuring informed decision-making in urban planning. This approach will strengthen the foundation of LID assessments, making them more reliable and effective for sustainable urban development.
- sFinally, researching innovative financing models with economic incentives, such as tax breaks, could encourage more businesses and individuals to adopt LID practices. Analyzing the impact of these incentives on adoption rates and project scalability will provide valuable insights for future initiatives.

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APPENDIX A: Tool Verification

EXAMPLE CASE 1

For example case 1 verification, user inputs shown in Table A1 were utilized to verify tool outcome depicted in Figure A1. The hand-calculated values shown in Table A2 for costs, benefits, and benefit scoring aligned with the values derived from literary inputs across sheets. This verified the accuracy of calculations performed using the tool.

Table A1 User Inputs for Example 1

Example Case 1 Inputs: Charlotte_BI	
Location Details:	
County	Mecklenburg
City	Charlotte, NC 28209, US
Census Tract Code	37119005519
LID BMP Details:	
Implemented BMP Type	Roadside Vegetation
Footprint (ft^2)	0.870 ha or 93646 SF
Project Objective	Equal Weightage

S1_Anticipated Outcomes of Selected Low Impact Development		
Selected LID		**Roadside Vegetation**
Overall Score / 10		**4.9**
Construction Costs ($)	$	65,553.00
Annual Maintenance Costs ($/yr)	$	11,238.00
Total Costs	**$**	**76,791**
Enhanced Property Value Per Household ($)	$	2,868
Savings from Improved Flood Mitigation ($/ FE)	$	32,037.00
Savings from Avoided Carbon Emissions ($/yr)	$	937.00
Annual WTP for Recreational Areas ($/yr)	$	21,093.00
Annual WTP (Water Quality & Aquatic Habitat Improvements) ($/yr)	$	16,699.00
Total Benefits	**$**	**73,634**

Figure A1 Example case 1 DST outcome

Table A2 Example case 1 hand calculation values

S1_ Hand Calculation Results	
Selected LID	Roadside Vegetation
Overall Score /10	$= (1.1 \times 4) + 1.3 + 1 + 1 + 2$ $= 4.9$
Construction Costs ($)	$= Unit\ Cost\ \times LID\ Footprint$ $= 0.7 \times 93646$ = 65,552.2 = 65,553
Annual Maintenance Costs ($/yr)	$= Unit\ Cost\ \times Footprint\ of\ LID\ BMP$ $= 0.12 \times 93646$ $= 11{,}237.52\ = 11{,}238$
Total Costs	$= \sum Sum\ of\ Costs$ $= 76{,}789.72 = 76{,}791$
Enhanced Property Value Per Household ($)	$=\ Current\ Property\ Value\ \times\ \ Property\ Increase\ Rate$ $=415{,}606 \times 0.69\%$ $= 2{,}867.68 = 2{,}868$
Savings from Improved Flood Mitigation ($/ FE)	$= LID\ Intitial\ Costs\ \times 6 \times (100 - Flood\ Risk\ Percentile)\%$ $= 65{,}553 \times 6 \times (100 - 91.855)\%$ $= 32{,}035.75 = 32{,}036$
Savings from Avoided Carbon Emissions ($/yr)	$= (LID\ Footprint) \times (CO_2\text{Value of }\ Emissions)$ $= 93646 \times 0.01$ $= 936.46 = 937$
Annual WTP Recreational Areas ($/yr)	$=\ Pop\ \times Cost\ for\ Recreational\ Benefits\ per\ SF$ $=\ 1953 \times 10.80$ $= 21{,}092.4 = 21{,}093$
Annual WTP (Water Quality & Aquatic Habitat Improvements) ($/yr)	$= Pop\ \times PVC\ \times C_a$ $= 1953 \times 0.57 \times 15$ $= 16698.15 = 16699$
Total Benefits	$= \sum Sum\ of\ Benefits$ =73634

EXAMPLE CASE 2

For example case 2 verification, user inputs shown in Table A3 were utilized to verify tool outcome depicted in Figure A2. The hand-calculated values shown in Table A4 for costs, benefits, and benefit scoring aligned with the values derived from literary inputs across sheets. This verified the accuracy of calculations performed using the tool.

Table A3 User inputs for example case 2

Example Case 2 Inputs: Alexander_RP	
Location Details:	
County	Alexander
City	Taylorsville, NC 28681, US
Census Tract Code	37003040600
LID BMP Details:	
Implemented BMP Type	Retention Pond
Footprint (ft^2)	5.26 ha or 66182 SF
Project Objective	Hierarchical Priorities in order (Flooding, Awareness, Public Health and Well Being, Social Equity)

Selected LID		**Retention Pond**
Overall Score / 10		**6.8**
Construction Costs ($)	$	2,444,102.00
Annual Maintenance Costs ($/yr)	$	121,775.00
Total Costs	**$**	**2,565,877**
Enhanced Property Value Per Household ($)	$	556
Savings from Improved Flood Mitigation ($/ FE)	$	9,546,226.00
Savings from Avoided Carbon Emissions ($/yr)	$	1,324.00
Annual WTP for Recreational Areas ($/yr)	$	21,428.00
Annual WTP (Water Quality & Aquatic Habitat Improvements) ($/yr)	$	15,480.00
Total Benefits	**$**	**9,585,014**

Figure A2 Example case 2 DST outcome

Table A4 Example case 2 hand calculation values

	S2_ Hand Calculation Results
Selected LID	Retention Pond
Overall Score /10	$= (3 \times 1.1) + 1.2 + 2.1 + 3 + 2 + 2) \div 2$ $= 6.8$
Construction Costs ($)	$= Unit\ Cost\ \times LID\ Footprint$ $= 36.93 \times 66182$ $= 2{,}444{,}101.26 = 2{,}444{,}102$
Annual Maintenance Costs ($/yr)	$= Unit\ Cost\ \times Footprint\ of\ LID\ BMP$ $= 1.84 \times 66182$ $= 121{,}774.88 = 121{,}775$
Total Costs	$= \sum Sum\ of\ Costs$ $= 2{,}565{,}877$
Enhanced Property Value Per Household ($)	$= Current\ Property\ Value\ \times\ Property\ Increase\ Rate$ $= 241330 \times 0.23\%$ $= 555.059 = 556$
Savings from Improved Flood Mitigation ($/ FE)	$= LID\ Intitial\ Costs\ \times 6 \times (100 - Flood\ Risk\ Percentile)\%$ $= 2{,}444{,}102 \times 6 \times (100 - 34.90296)\%$ 9,546,226
Savings from Avoided Carbon Emissions ($/yr)	$= (LID\ Footprint) \times (CO_2\text{Value of } Emissions)$ $= 66{,}182 \times 0.02$ $= 1{,}323.64 = 1{,}324$
Annual WTP Recreational Areas ($/yr)	$= Pop\ \times Cost\ for\ Recreational\ Benefits\ per\ SF$ $= 1984 \times 10.80$ $= 21{,}427.2 = 21{,}428$
Annual WTP (Water Quality & Aquatic Habitat Improvements) ($/yr)	$= Pop\ \times PVC\ \times C_a$ $= 1984 \times 0.52\ \times 15$ $= 15{,}480$
Total Benefits	$= \sum Sum\ of\ Benefits$ $= 9{,}585{,}014$

APPENDIX B: Supplemental Data

Please click the following link to obtain the Excel-based Decision Support Tool (DST) for your convenience: [Download the Decision Support Tool] by clicking on this link.

Please download the excel file and run it only in Excel 360 as the formulas used in this tool may not be compatible with previous versions.