INTEGRATING INFILTRATION-BASED NATURE-BASED INFRASTRUCTURE IN COASTAL AREAS FOR SUSTAINABLE STORMWATER MANAGEMENT

by

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ABSTRACT

Coastal floodplain systems face heightened flood risks due to climate change, urbanization, and limitations of conventional stormwater practices. Existing infrastructure often lacks the adaptability and ecological benefits required to manage elevated water tables, storm surges, and heavy rainfall. This study evaluates infiltration-based strategies, focusing on Green Infrastructure (GI) and Conventional Infrastructure (CI) in St. Marys, Georgia—a coastal city vulnerable to tidal and rainfall flooding exacerbated by sandy soils and shallow groundwater. Using StormWise hydrological modeling, baseline, GI-enhanced, and CI-only scenarios are assessed for peak flow reduction, infiltration rates, flood extent, and groundwater recharge under varying rainfall intensities and tidal effects. Sensitivity analyses explore factors like soil permeability and vegetation coverage. Results indicate that GI systems improve infiltration, delay runoff peaks, and offer ecological co-benefits compared to CI. These findings address knowledge gaps, supporting sustainable flood management and resilient urban design in flood-prone coastal areas.

INDEX WORDS: Green Infrastructure, Conventional Infrastructure, Stormwater Management, Coastal Flooding, Hydrologic Modeling,

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CHAPTER ONE
INTRODUCTION

1.1 Context and Background

Coastal regions across the globe are increasingly threatened by flooding, a crisis deepened by the intersecting forces of climate change, rapid urban development, and outdated infrastructure. The rising frequency and intensity of flood events are no longer anomalies but consistent patterns, reshaping landscapes and livelihoods. According to the Intergovernmental Panel on Climate Change (IPCC, 2021), global sea levels are projected to rise significantly over the next century, driven by glacial melt and thermal expansion, which compound the risks already posed by extreme rainfall and storm surges. Low-lying coastal cities, in particular, face a convergence of multiple flood drivers: rainfall-induced flooding, tidal inundation, and storm surge events.

Rainfall-driven flooding arises from heavy or prolonged precipitation that exceeds the soil's infiltration capacity or the drainage system's design thresholds. This type of flooding is sensitive not only to rainfall volume but also to antecedent moisture conditions extended dry spells can lead to surface crusting, reducing infiltration, while already saturated soils during the wet season accelerate runoff (Leandro et al., 2016). Tidal flooding, on the other hand, is influenced by lunar cycles, sea-level anomalies, and land subsidence, with chronic "sunny day" flooding becoming more frequent in cities like Miami and Charleston. Storm surges sudden rises in water levels during tropical cyclones exert a catastrophic impact when they coincide with high tides, especially in flat, low-lying areas (Nicholls et al., 2007).

In response to these complex and interconnected threats, stormwater management has traditionally relied on Conventional Infrastructure (CI) systems—engineered structures such as culverts, detention basins, stormwater pipes, and channelized drains. While these solutions aim to convey excess water away from urban areas, they are often rigid, centralized, and incapable of adapting to variable or changing hydrological conditions (Ashley et al., 2005). Moreover, such systems typically fail to account for the ecological and groundwater needs of coastal environments, often leading to unintended consequences such as erosion, water quality deterioration, and habitat loss.

In contrast, Green Infrastructure (GI) and Nature-Based Solutions (NBS) have emerged as more flexible, sustainable alternatives. These approaches mimic natural hydrological processes by enhancing infiltration, promoting evapotranspiration, and restoring ecological connectivity. GI interventions such as bioswales, permeable pavements, rain gardens, and green roofs not only manage runoff volumes but also support biodiversity, improve air and water quality, and mitigate urban heat island effects (Fletcher et al., 2015).

1.2 Problem Statement

Despite advances in urban water management, existing stormwater systems in coastal areas remain ill-equipped to manage the intensifying pressures of climate variability and urban sprawl. These deficiencies are particularly evident in coastal cities where stormwater systems are frequently compromised by shallow groundwater tables, high tidal ranges, and saltwater intrusion. Traditional CI in these settings is not designed to absorb or infiltrate water; instead, it prioritizes rapid drainage, which can overwhelm downstream systems and exacerbate local flooding. In addition, such systems often neglect the ecological co-benefits and groundwater recharge opportunities that are critical in coastal zones.

In the city of St. Marys, Georgia a low-elevation urban area located along the Atlantic coast—these issues are particularly acute. The city is routinely exposed to tidal flooding, rainfall-induced inundation, and seasonal storm surges. The sandy soils that define much of the region may aid infiltration, but the high-water table limits the soil's absorptive capacity, often leading to surface pooling and prolonged drainage times. Urbanization in the area has introduced more impervious surfaces, further exacerbated runoff volumes and reducing the land's natural flood-buffering capacity.

While GI has shown promise in managing stormwater in various urban settings, there is a critical lack of research that quantifies its performance in coastal cities characterized by shallow groundwater and tidal influence. There is also limited understanding of how hybrid approaches those that blend GI and CI compare to conventional systems in such environments. This research seeks to address that knowledge gap by modeling and evaluating multiple infrastructure configurations using site-specific data and flood scenarios in St. Marys.

1.3 Research Questions

The primary research question we addressed in this study was:

> How do GI approaches compare with CI methods in managing stormwater and reducing flooding in tidally influenced coastal cities such as St. Marys, Georgia?

To answer the above questions, the following sub-questions were identified:

1. How effectively does GI manage rainfall-driven flooding compared to CI during typical seasonal rainfall events in St. Marys, Georgia?
2. How do GI strategies affect groundwater recharge compared to CI under different rainfall characteristics?

1.4 Research Objectives

The primary aim of this research is to evaluate and compare the hydrologic performance of GI, and CI, strategies in coastal environments prone to multiple flood drivers.

The objectives of this study are as follows:

1. **Evaluating the Effectiveness of Green Infrastructure (GI) and Conventional Infrastructure (CI) in Managing Flood Risks:**

   This objective involves investigating the comparative performance of GI and CI systems in mitigating flood risks across various scenarios, including frequent minor flooding events, heavy rainfall, and extreme storms. Metrics such as flood depth reduction, peak flow attenuation, infiltration rates, runoff reduction, and time-to-drainage will be assessed using the StormWise hydrological model and geospatial analysis.

2. **Understanding the Adaptive Capacity of Green Infrastructure (GI) to Environmental Changes:**

   This research explores the dynamic performance of GI systems under environmental changes such as variations in soil permeability, sedimentation, and vegetation growth. Scenario-based modeling will be employed to evaluate the resilience and adaptability of these systems, providing insights into their long-term functionality.

3. **Exploring the Role of Specific Green Infrastructure Features in Hydrologic Performance:**

   This study highlights the hydrologic contributions of specific GI features, such as rain gardens. While individual contributions will not be modeled, their cumulative impact on infiltration, peak flow reduction, and groundwater recharge will be emphasized as key components of sustainable stormwater management.

1.5 Significance of the Study

This study contributes to the growing body of research on sustainable stormwater management by providing a comprehensive comparative analysis of GI and CI in a coastal setting. The application of StormWise hydrological modeling in a tidally influenced, shallow-groundwater environment represents a novel methodological approach, particularly in the context of scenario-based planning and sensitivity testing. By addressing an understudied yet critical context coastal floodplains this research fills a crucial gap in existing literature and offers insights that are transferable to similar urban environments globally.

For urban planners, civil engineers, and policymakers in St. Marys and comparable cities, the findings of this study offer data-driven guidance on infrastructure investments and adaptation strategies. By quantifying the trade-offs and synergies among GI and CI the research provides a foundation for integrating nature-based solutions into conventional urban development frameworks. It supports decision-making for zoning laws, floodplain management, green space design, and maintenance planning, especially as climate stressors become more unpredictable.

Beyond the immediate application to flood mitigation, this study aligns with broader goals of climate resilience, sustainability, and community well-being. GI solutions not only protect infrastructure but also enhance public health, restore urban ecosystems, and promote social equity by creating multifunctional spaces. As climate change increasingly impacts vulnerable populations, especially in coastal areas, adopting adaptive, nature-based strategies becomes not just a technological need but a social imperative.

This thesis is organized into five chapters. Chapter One introduces the research problem, provides the context, outlines the objectives, and explains the study's significance. Chapter Two presents a detailed review of the literature on stormwater management, flood risk in coastal cities, and the theoretical foundations of GI and CI systems. Chapter Three outlines the methodology, including model configuration, data collection, calibration, and scenario development using StormWise. Chapter Four presents and analyzes the results of the simulations, comparing the performance of different infrastructure strategies across various flood conditions. Chapter Five discusses the findings considering existing research, draws key conclusions, and outlines practical recommendations for planners, as well as suggestions for future research.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

As climate change accelerates, coastal regions are increasingly exposed to compound flooding risks driven by rising sea levels, intense rainfall events, and tidal surges. Conventional stormwater systems, typically designed for predictable runoff volumes, are proving insufficient in these dynamic, low-lying environments (Roy et al., 2008). Infiltration-based stormwater infrastructure including green and nature-based solutions has gained traction for its ability to manage runoff, enhance infiltration, and reduce peak flows, particularly in flood-prone coastal landscapes. These systems mimic natural hydrological processes, restoring ecological balance while improving flood resilience.

This chapter explores the growing body of literature on infiltration-based approaches to stormwater management. Emphasis is placed on GI and nature-based solutions (NBS), with attention to their performance, adaptability, and application in coastal contexts. The chapter also examines theoretical frameworks like the Social-Ecological-Technological Systems (SETS) and to contextualize the shift from rigid conventional infrastructure toward more adaptive, integrated systems. Advanced hydrological modeling tools, including StormWise, are discussed as critical instruments for simulating these systems under real-world climate conditions.

The literature review proceeds thematically. Section 2.2 introduces GI, focusing on design principles, benefits, challenges in coastal zones, and policy frameworks. Section 2.3 extends this discussion into broader NBS applications, supported by resilience theory and biodiversity considerations. Section 2.4 reviews SETS followed by Section 2.4 on hydrological modeling tools. Section 2.5 evaluates the specific capabilities and challenges of the StormWise platform. Section 2.6 compares GI with CI in terms of hydrologic performance, and Section 2.7 synthesizes key insights and outlines future research directions. By reviewing the strengths and limitations of these approaches, this chapter provides a foundation for understanding how integrated stormwater infrastructure can support sustainable flood management in vulnerable coastal environments.

2.2 Green Infrastructure for Stormwater Management

GI refers to a network of engineered systems that emulate natural processes to manage stormwater through infiltration, evapotranspiration, and storage (Sutton-Grier et al., 2018). Unlike conventional drainage, which emphasizes rapid water removal, GI slows and absorbs runoff at or near its source, restoring the hydrological cycle disrupted by impervious surfaces. Key GI types include rain gardens, bioswales, green roofs, urban forests, and permeable pavements.

These systems are built on the principle of biomimicry designing urban features that replicate the functionality of natural ecosystems. Bioswales, for example, are vegetated channels that convey and filter runoff while encouraging infiltration. Permeable pavements allow rainfall to pass through their surface layers, reducing surface pooling and pressure on drainage networks. The inclusion of engineered soils and native vegetation enhances both water absorption and ecological performance (Li et al., 2018).

By reducing the velocity and volume of stormwater, GI mitigates urban flooding while improving groundwater recharge. These systems can be installed at multiple scales from individual parcels to city-wide networks and offer flexibility in design and implementation. Their decentralized nature allows them to complement existing infrastructure while contributing to a city's climate resilience and sustainability goals (Sutton-Grier et al., 2018).

The multifunctional benefits of GI have been widely documented in both academic and planning literature. Hydrologically, GI reduces peak flow rates and delays runoff timing, thereby decreasing the likelihood of urban flooding (Chang et al., 2021). In urbanized areas with limited pervious surfaces, GI features like rain gardens and green roofs absorb rainfall where it lands, reducing the burden on piped drainage systems and lowering the risk of combined sewer overflows.

Environmental benefits are another major strength of GI. As runoff passes through vegetated systems, pollutants such as sediments, oils, and heavy metals are naturally filtered out before reaching water bodies (Li et al., 2018). This process contributes significantly to water quality improvements and aligns with water protection mandates.

GI also plays a critical role in urban cooling. The urban heat island (UHI) effect, caused by heat-absorbing surfaces like asphalt and concrete, intensifies temperature extremes. GI counteracts this by introducing vegetation that cools through evapotranspiration, improving thermal comfort and reducing the energy demand for air conditioning (Sutton-Grier et al., 2018). Green roofs and urban tree canopies are especially effective in moderating temperatures and providing shade.

Social and ecological co-benefits include enhanced biodiversity, aesthetic improvements, and recreational spaces. Green roofs and bioswales can be designed as habitats for pollinators and other wildlife, contributing to ecological connectivity in urban landscapes. In addition, the visual appeal and multifunctionality of GI increase community acceptance and promote wellbeing (Sutton-Grier et al., 2018; Norton et al., 2015). Overall, GI transforms stormwater from a waste product into a resource, delivering hydrologic services alongside social and ecological value.

2.2.1 Challenges in Coastal Environments

Despite its many advantages, GI faces unique implementation challenges in coastal floodplains. One of the primary barriers is the presence of shallow groundwater tables, which reduce the soil's capacity to absorb additional water during rainfall events. When the water table is close to the surface, infiltration slows, limiting the effectiveness of traditional GI features like bioswales or infiltration trenches (Saleh et al., 2016).

Saltwater intrusion presents an additional threat. Coastal GI systems are increasingly exposed to saline water during high tides and storm surges, which can degrade soil structure and damage non-adapted vegetation. This undermines the system's filtration and absorption capacity over time. Saleh et al. (2016) found that repeated salt exposure could significantly impair the performance of GI, particularly in areas lacking adaptive design strategies.

To address these limitations, coastal GI must incorporate context-specific adaptations, such as salt-tolerant plant species, permeable substrates resistant to saline corrosion, and raised or layered soil profiles. Subsurface drainage and elevated bioswales can also help maintain performance in saturated conditions. These modifications, while necessary, may increase costs and complexity. Nonetheless, they are essential for sustaining GI function in vulnerable coastal areas subject to compound flood dynamics.

2.2.2 Policy and Planning Integration

Policy frameworks increasingly recognize GI as an essential component of sustainable urban planning. At the municipal level, cities have adopted GI standards within building codes and stormwater regulations, requiring developments to integrate rain gardens, green roofs, and permeable pavements (Chang et al., 2021). These mandates are often supported by incentives such as stormwater fee credits, expedited permitting, or grant programs, encouraging private-sector participation.

On a broader scale, the European Commission (2013) has promoted GI through strategies aimed at enhancing ecological connectivity and climate resilience. Martin et al. (2020) emphasize that GI is not only a tool for stormwater control but also a pillar of regional climate adaptation. The integration of GI into land use planning helps reduce long-term vulnerability to climate extremes and aligns with biodiversity and green space conservation efforts. Community engagement further strengthens GI implementation. Public participation in the design and stewardship of GI through volunteer tree planting, garden maintenance, or participatory planning—fosters local ownership and environmental literacy (Chang et al., 2021). Such engagement ensures that GI systems are better maintained and more responsive to neighborhood needs, reinforcing their long-term resilience and functionality within urban systems.

2.3 Nature-Based Solutions (NBS) and Resilience Theory

2.3.1 NBS as an Extension of GI

Nature-based solutions (NBS) build upon the principles of GI by encompassing a broader range of interventions that restore, manage, or emulate natural ecosystems to address societal challenges. While GI is largely rooted in urban planning and stormwater engineering, NBS expands into coastal and rural contexts with strategies like mangrove restoration, wetland creation, dune stabilization, and living shorelines (IUCN, 2020).

NBS delivers multifunctional benefits by leveraging intact or rehabilitated ecosystems to provide flood protection, carbon sequestration, water purification, and biodiversity enhancement (Raymond et al., 2017). For instance, mangrove belts along tropical coasts can reduce wave energy by up to 66%, buffering inland areas from storm surge damage (Meerow, 2017). Wetlands and floodplain restoration serve as natural detention basins, mitigating downstream flooding while improving habitat quality.

Unlike traditional infrastructure, which often serves a single purpose, NBS simultaneously enhances ecosystem services and community resilience. Sutton-Grier et al. (2018) describe NBS as a strategy that increases environmental health while addressing infrastructure vulnerabilities. This dual focus allows NBS to support long-term climate adaptation in complex and sensitive environments. By incorporating NBS into urban and regional planning, communities gain sustainable tools to confront escalating flood risks without compromising ecological integrity or social equity.

2.3.2 Resilience Theory in NBS

Resilience theory provides a conceptual lens through which to understand the robustness of Nature-Based Solutions in the face of environmental variability. Resilience refers to the ability of a system to absorb disturbances, adapt to stress, and continue to function without collapsing into an entirely different state. In flood management, this translates to infrastructure systems that can withstand extreme weather while maintaining hydrologic performance and ecological value (Keesstra et al., 2018).

In coastal floodplains, resilience is enhanced by biological and structural diversity. Wetlands with a range of plant heights and salt tolerances can absorb variable floodwaters while continuing to function under tidal influence. Adaptive capacity increases with biodiversity, enabling systems to self-regulate and recover from disturbances (Keesstra et al., 2018). Adaptive management is a critical component of resilient NBS, involving monitoring, evaluation, and iterative adjustments to account for changing conditions (Saksena et al., 2019). Resilience theory also supports a shift from rigid to flexible infrastructure systems. Traditional CI is often static and difficult to modify. NBS, by contrast, evolves with its environment. Remote sensors and field-based data collection tools can monitor water levels, sedimentation rates, and vegetation health, allowing real-time interventions that maintain system performance. This dynamic adaptability is key to sustaining flood mitigation and ecological services over time.

2.3.3 Community Participation and Biodiversity Benefits

The long-term viability of Nature-Based Solutions depends significantly on community involvement and ecological diversity. Saksena et al. (2019) emphasizes that adaptive NBS systems require routine observation and maintenance, which are more effective when local stakeholders are engaged. Community participation enhances social ownership, increases monitoring coverage, and ensures that NBS designs align with local needs and knowledge systems.

Participatory approaches also contribute to ecological resilience. Local involvement in planting, maintaining, and observing systems can identify subtle changes in hydrology or plant health that may not be captured through remote sensing. Community stewardship further improves public understanding of flood risks and fosters shared responsibility for resilience-building efforts.

Simultaneously, NBS supports biodiversity through habitat creation and restoration. Constructed wetlands, living shorelines, and reforested floodplains provide habitat for fish, birds, and pollinators while also offering human benefits like shade and recreational access (Keesstra et al., 2018). The presence of diverse flora and fauna not only enhances ecological richness but also increases system redundancy and functional resilience. In this way, biodiversity and community engagement become mutually reinforcing pillars of sustainable flood mitigation in coastal environments.

2.4 SETS Framework

2.4.1 Overview of SETS

The Social-Ecological-Technological Systems (SETS) framework offers a comprehensive lens through which to examine urban flood resilience, particularly in vulnerable and rapidly evolving coastal environments. Traditional infrastructure planning often isolates technological systems from their social and ecological contexts. In contrast, SETS emphasizes the interdependence among these three domains, acknowledging that resilient stormwater and floodplain management must account for not only engineered design, but also ecological dynamics and human behavior (Markolf et al., 2018; Sharifi, 2023). This systems-based perspective is increasingly critical as urban areas face compounding risks from climate change, such as sea level rise, tidal surges, and intensifying storm events.

Within the SETS framework, the social dimension encompasses governance structures, institutional capacity, equity concerns, and community engagement. Public acceptance of infrastructure, the effectiveness of policy instruments, and participatory decision-making all directly affect how GI, and Nature-Based Solutions (NBS) are implemented and maintained. The ecological domain focuses on the restoration and preservation of natural processes that contribute to resilience, including infiltration, evapotranspiration, habitat connectivity, and soil regeneration. These ecological functions are central to the long-term performance and co-benefits of GI systems, such as rain gardens, wetlands, and permeable surfaces.

The technological domain incorporates both the physical infrastructure—such as conventional conveyance systems, detention basins, and hybrid GI/CI systems—and the digital tools used to simulate, monitor, and manage hydrologic behavior. Hydrological models like StormWise, PC-SWMM, and MIKE FLOOD are instrumental in evaluating system performance under current and future stressors. In coastal cities, SETS encourages an adaptive infrastructure approach—where the system evolves in response to changing climate conditions, land use, and societal needs. Rather than treating infrastructure as a static entity, the SETS approach supports integrated strategies that are ecologically sound, socially inclusive, and technologically agile.

2.5 Role of Hydrological Modeling in GI/NBS Applications

Hydrological modeling is a cornerstone of flood risk assessment and stormwater infrastructure design, especially as climate change and urbanization increase the intensity and frequency of flooding. These models simulate the movement and storage of water across landscapes, enabling planners to assess how rainfall translates into runoff, how quickly water moves through a catchment, and where flooding may occur. Tools like PC-SWMM (CHI, 2020), MIKE FLOOD (DHI, 2023), and StormWise (Streamline Technologies, n.d.) are widely used to evaluate flood extents, timing, and infrastructure response under various scenarios. In urban areas, where impervious surfaces limit natural infiltration, such simulations help identify critical flood zones, support zoning decisions, and inform stormwater control strategies.

One of the key applications of these models is evaluating the performance of GI and NBS. These approaches depend on dynamic hydrologic processes like infiltration, evapotranspiration, and groundwater recharge. Models allow practitioners to simulate how bioswales, rain gardens, or permeable pavements perform under different soil types, rainfall intensities, and moisture conditions. When calibrated correctly, they also estimate co-benefits such as pollutant reduction or enhanced baseflow. For example, StormWise simulations have shown that hybrid systems can reduce flood extents by up to 40% in Gulf Coast settings (Del Angel, 2021), while NYC DEP

(2020) found that green infrastructure could cut peak flows by 35% during a 10-year storm. By incorporating Global Climate Model (GCM) projections, hydrologic tools also test long-term system robustness under future sea-level rise, storm surge, or prolonged rainfall events, making them critical for climate-resilient urban design (Hirabayashi et al., 2013).

Despite their benefits, these tools come with limitations. High-quality inputs such as topography, soil profiles, and rainfall data are not always available, especially in smaller municipalities or resource-limited regions (Saksena et al., 2019). Moreover, the technical complexity of tools like MIKE FLOOD or StormWise requires skilled users, and without proper calibration and interpretation, models can mislead rather than inform (Wright et al., 2020). Institutional barriers also persist—budget cycles, siloed decision-making, and uncertainty around climate projections often prevent model-informed strategies from being implemented in policy. However, improvements in remote sensing, cloud computing, and open-source platforms (e.g., HEC-HMS, SWMM) are reducing technical and financial entry barriers. As visual tools, models also serve as powerful communication aids—3D animations and flood maps help convey the value of GI/NBS to the public and policymakers alike.

2.6 StormWise Modeling in Coastal Flood Management

StormWise, formerly known as Interconnected Channel and Pond Routing version 4 (ICPR4), is a sophisticated hydrologic and hydraulic modeling platform designed to simulate complex stormwater behavior in urban and coastal environments. Its ability to integrate rainfall, overland flow, tidal surge, and groundwater interactions makes it especially suitable for compound flooding assessments. In regions like St. Marys, Georgia—where flood risks stem from a combination of fluvial, pluvial, and tidal influences—StormWise enables a unified modeling approach that captures these interconnected processes. Using the Saint-Venant equations for open-channel flow and the Green-Ampt method for soil infiltration, the model provides robust simulation of both engineered and nature-based stormwater infrastructure, such as detention basins, bioswales, and permeable pavements (Tanim et al., 2022).

StormWise excels in evaluating how different stormwater infrastructure perform under varied storm scenarios, sea-level rise conditions, and soil characteristics. By enabling users to construct multiple design configurations, it functions as both a planning and decision-support tool. Case studies illustrate its real-world value: Del Angel (2021) demonstrated that hybrid systems simulated in StormWise reduced flood extent by up to 40% in the Northern Gulf of Mexico, while Schroeder et al. (2022) found that GI features in Florida reduced total runoff by up to 36% and significantly delayed peak flows. These results informed regional stormwater design strategies, emphasizing the importance of flexible, nature-based approaches in flood-prone areas.

Despite its advantages, StormWise requires high-quality input data—such as detailed topography, land cover, and precipitation records—to generate accurate outputs. This can pose challenges for smaller municipalities with limited data or technical capacity (Saksena et al., 2019). However, integration with Geographic Information Systems (GIS) and cloud computing platforms has improved data accessibility and reduced computational burdens. Beyond technical capabilities, StormWise also supports effective communication with stakeholders by generating visual outputs like flood maps and hydrographs, helping bridge the gap between science and public understanding. As urban areas continue to face climate uncertainty, the model's capacity to simulate compound flooding and evaluate adaptive, ecosystem-based infrastructure makes it a vital tool for resilient stormwater planning.

2.7 Comparative Evaluation of GI and CI in Coastal Floodplain Systems

Comparing GI and CI within the context of coastal floodplain management reveals distinct advantages and limitations across both systems. While CI has historically served as the backbone of urban drainage and flood protection, GI is increasingly being adopted for its multifunctional, adaptive capabilities. Understanding their comparative performance is crucial in selecting context-specific solutions, particularly in coastal regions where stormwater dynamics are complex and compounded by tidal, pluvial, and fluvial influences.

Conventional Infrastructure is characterized by engineered systems designed to collect and convey stormwater rapidly away from urban areas. These systems include detention basins, underground pipes, culverts, and floodwalls structures built for predictability and capacity. CI is highly effective during high-intensity events that generate large volumes of runoff, particularly when rapid drainage is necessary to protect critical infrastructure (Saksena et al., 2019). For example, underground storm drains, and concrete channels can prevent street flooding by quickly diverting water to nearby outfalls. In addition, CI designs often follow standardized engineering practices, making them easier to regulate and maintain within existing municipal frameworks.

However, the rigidity of CI presents limitations, especially in coastal zones facing evolving climate risks. CI typically does not promote infiltration or groundwater recharge, and it provides little flexibility to accommodate fluctuating conditions such as sea-level rise or increased storm surge frequency (Ahern, 2011). Furthermore, CI often leads to negative ecological consequences, including stream channelization, habitat degradation, and the transport of polluted runoff directly into receiving waters (Brody et al., 2007). These trade-offs have prompted urban planners and environmental engineers to seek more adaptive, nature-integrated alternatives.

Green infrastructure offers an alternative paradigm by emulating natural hydrological processes to manage runoff. Systems such as bioswales, permeable pavements, green roofs, and rain gardens reduce runoff volume, enhance infiltration, and improve water quality (Sutton-Grier et al., 2018). GI also contributes significantly to urban cooling, biodiversity, and community well-being, making it an attractive option for cities aiming to meet both environmental and social goals.

In coastal floodplains, GIs decentralized, surface-level design is particularly useful for managing frequent, low- to moderate-intensity rainfall events and for enhancing the resilience of local ecosystems (Chang et al., 2021). However, GI systems can become overwhelmed during high-magnitude storm events, particularly in areas with shallow groundwater or saline intrusion. These challenges necessitate careful site assessment and adaptive design, including salt-tolerant vegetation and layered substrates, to maintain long-term functionality (Saleh et al., 2016).

Hybrid systems that integrate the strengths of both CI and GI are emerging as a practical approach to managing coastal flood risks. For instance, combining permeable surfaces with traditional conveyance systems allows for both infiltration during minor storms and rapid drainage during major events. These systems balance engineered predictability with ecological adaptability, offering a layered defense against both current and future flood hazards (Liao, 2014).

In summary, GI and CI each serve distinct roles in floodplain management. CI remains essential for managing extreme events and safeguarding critical infrastructure, while GI provides sustainable, multi-benefit solutions that enhance urban and ecological resilience. In coastal environments, where both intensity and complexity of flood risks are increasing, hybrid approaches that leverage the best of both systems present the most promising pathway forward.

2.8 Conclusion and Future Research Directions

The literature reviewed in this chapter underscores the growing importance of integrated, infiltration-based approaches to stormwater management in coastal floodplains. GI and NBS have emerged as viable alternatives or complements to CI, offering not only hydrologic benefits such as flood mitigation and runoff reduction but also critical co-benefits including groundwater recharge, improved water quality, biodiversity enhancement, and urban cooling. These systems are especially pertinent in vulnerable coastal cities, where complex interactions between rainfall, tides, storm surges, and shallow groundwater conditions make traditional drainage methods insufficient.

The SETS framework provides valuable theoretical scaffolding for understanding the multidimensional shifts required to implement resilient infrastructure. SETS highlights the necessity of addressing social, ecological, and technological components together in an integrated manner. It emphasizes that successful flood resilience strategies must consider the interplay between community values and engagement, ecosystem processes, and engineering solutions. Case studies from New York City, Scotland, and San Francisco illustrate how real-world applications of the SETS framework can guide successful implementation of sustainable stormwater systems, even in diverse geographical and governance contexts.Hydrological modeling plays a pivotal role in designing and evaluating GI, NBS, and hybrid systems. Tools like StormWise offer the ability to simulate complex coastal flooding scenarios, including compound events driven by rainfall and tidal surges. These models support data-driven planning, optimize infrastructure layouts, and provide compelling visual outputs that help communicate risk and justify investment. However, modeling is not without challenges: it requires high-resolution input data, technical expertise, and institutional capacity that are not always available at the local level.

Recent advances in GIS integration, remote sensing, and cloud computing are helping to lower these barriers.

Comparative evaluation between GI and CI reveals that while CI remains essential for large-scale, high-intensity flood protection, it lacks the adaptability and ecological co-benefits of GI. In contrast, GI systems are particularly effective at managing frequent, lower-intensity events and promoting long-term urban and ecological resilience. Hybrid systems, combining the strengths of both approaches, are gaining recognition as optimal strategies for coastal cities seeking to address compound and evolving flood risks.

Despite the growing body of knowledge, several research gaps remain. Future studies should prioritize community-based assessments of GI and NBS, especially in coastal settings where public engagement is essential for long-term functionality. Local participation enhances system stewardship, informs culturally appropriate design, and improves social resilience. Additionally, more longitudinal studies incorporating climate change scenarios are needed to test the durability of infiltration-based systems under sea-level rise, increased storm intensity, and changing precipitation regimes.

Further empirical comparisons of GI and CI not just in terms of hydrologic performance but also lifecycle costs, maintenance demands, and ecological returns will help guide municipalities toward more cost-effective and sustainable infrastructure choices. Another area requiring attention is policy integration: translating model outputs into enforceable regulations, funding priorities, and zoning policies remains a challenge. Research should explore how to better incorporate advanced modeling tools like StormWise into local and national planning frameworks.

Lastly, interdisciplinary research using the SETS framework should be expanded. Flood resilience is not merely a technological issue; it involves navigating trade-offs across social justice, ecological integrity, and engineering feasibility. Cross-sectoral collaboration among hydrologists, urban planners, ecologists, and policymakers will be vital in designing infrastructure systems that are not only functional but also inclusive and future-ready.

In conclusion, sustainable stormwater management in coastal floodplains demands a paradigm shift one that embraces flexibility, functionality, and community co-benefit. The integration of GI, NBS, and advanced modeling, underpinned by frameworks like SETS and , offers a comprehensive path forward. As climate risks escalate, cities that adopt these integrated approaches will be better positioned to protect their communities, restore their ecosystems, and build long-term resilience.

CHAPTER THREE
METHODS

3.1 Study Area Description

This section provides a comprehensive characterization of St. Marys, Georgia, detailing its geographical, geological, climatic, and hydrological attributes. This detailed exposition is critical for understanding the city's inherent susceptibility to flooding and for contextualizing the subsequent evaluation of various stormwater management strategies. Crucially, while St. Marys is the broader study locale, the specific focus of this research is a major roadway corridor within the city, locally known as "the spine," which has a documented history of frequent surface flooding during moderate rainfall events. This particular segment was chosen due to its high vulnerability, its critical role as a transportation artery, and its representativeness of similar flood-prone urban areas in coastal cities with shallow groundwater and tidal influences.

3.1.1 Geographic and Topographic Context

The research focuses on St. Marys, Georgia, a dynamic coastal city situated in Camden County, within the southeastern United States. Its strategic location on the Atlantic coast, near the Florida border, inherently exposes the city to a complex interplay of coastal hydrological processes. Topographically, St. Marys is characterized by a low-lying floodplain and remarkably low gradient, features that significantly contribute to its vulnerability to various forms of inundation (Federal Emergency Management Agency [FEMA], 2007). Extensive estuarine systems and tidal marshes further define the landscape, acting as natural interfaces between land and water. These topographical characteristics collectively render the region particularly susceptible to flooding originating from storm surges, tidal effects, and intense precipitation events.

The city's hydrology is profoundly influenced by the St. Marys River and its immediate proximity to the Atlantic Ocean. This dual influence creates complex interactions between freshwater runoff and coastal flood dynamics. The flat terrain inherently impedes rapid gravitational drainage, meaning that water tends to accumulate rather than flow swiftly away. When combined with the low-lying nature of the area and its direct connection to major waterways, inland rainfall-driven flooding is frequently exacerbated by rising external water levels. This confluence of factors means that St. Marys faces a multifaceted flood challenge, where multiple drivers of rainfall, riverine flows, tidal fluctuations, and potential storm surges converge, intensifying the overall flood vulnerability. Consequently, effective stormwater management strategies in this region must adopt a holistic approach, addressing not just individual flood sources but their compounding effects to build comprehensive resilience.

Figure 3.1: Aerial view of St. Marys, Georgia, with the spine highlighted within the orange oval; a) location of St. Marys within the state of Georgia, and groundwater and rainfall monitoring sites marked b) City Smitty Street (inland) and c) Boat Ramp (tidally-influenced).

3.1.2 Climatic Profile and Rainfall Characteristics

St. Marys experiences a humid subtropical climate, characterized by hot, humid summers and mild winters, with distinct seasonal rainfall patterns that significantly affect stormwater management (NOAA, 2023). The region receives most of its precipitation during the summer months, particularly between June and September, which coincide with both the wet season and the Atlantic hurricane season. On average, St. Marys receives approximately 55 inches of rainfall annually, with August being the wettest month. Short-duration, high-intensity storm events are common during this period, with peak rainfall intensities reaching 3 to 5 inches per hour during severe convective or tropical storms (NOAA Atlas 14, 2023). These hydrologic conditions place substantial and recurring stress on local drainage infrastructure, particularly in low-lying and tidally influenced areas.

The consistent and intense precipitation, characteristic of a humid subtropical climate and amplified by hurricane season, places a continuous and often overwhelming demand on existing stormwater infrastructure. Such systems may not have been originally designed to manage these volumes or the compounding effects of coastal dynamics. This environmental reality necessitates a fundamental shift towards more robust and adaptive infrastructure solutions. These solutions must be capable of effectively managing both the high volume and intense rates of precipitation, moving beyond outdated designs to ensure long-term sustainability and flood resilience. This underscores the critical need for flood management strategies that can effectively handle both short-term, high-intensity rainfall events and longer-duration inundation periods, especially when these are compounded by coastal influences. In addition to rainfall, tidal backwater effects play a central role in generating compound flooding in St. Marys. The study domain is directly influenced by the Atlantic Ocean through the St. Marys River and Cumberland Sound, making tidal fluctuations a persistent hydrodynamic force. Based on NOAA tidal gauge data from nearby Fernandina Beach (Station ID: 8720030), the mean tidal range in the region is approximately 6.4 feet (1.95 meters), with high tides frequently reaching or exceeding 3.2 feet (NAVD88) during spring tide events. High tides occur twice daily due to the semi-diurnal tidal regime and can persist near peak elevation for 1–2 hours depending on lunar and meteorological conditions. In this study, tidal stage data were incorporated as a dynamic boundary condition at the downstream edge of the model to simulate realistic backwater effects. This is especially important during intense rainfall events when elevated tides can restrict drainage, leading to tidal locking of outfalls and prolonged surface inundation. The interaction of tidal backflow with rainfall-driven runoff is central to understanding the system's hydrologic performance under compound flooding scenarios. These tidal dynamics are critical for evaluating long-term adaptation strategies in coastal areas like St. Marys, where future sea-level rise may amplify high tide frequencies and exacerbate compound flood risks.

3.1.3 Geological and Soil Characteristics

The geological and soil characteristics of St. Marys present significant challenges to effective stormwater management. The study area includes a natural soil map unit known as the Bohicket–Capers association, along with distinct soil series such as Tisonia mucky peat, Cainhoy fine sand, and Mandarin fine sand. These soils represent a wide range of hydrologic and physical properties. The Tisonia and Bohicket–Capers soils are classified as very poorly drained tidal marsh soils, with textures ranging from silty clay to mucky peat, and fall within hydrologic soil group (HSG) D, indicating very slow infiltration rates (USDA NRCS, 2023a; Soil Survey Staff, 2023). In contrast, Cainhoy and Mandarin series are fine sandy soils that are moderately well- to well-drained, typically assigned to HSG A or B due to their higher permeability and infiltration capacity (USDA

NRCS, 2023b). It is important to note that in urbanized environments, soils are frequently modified through grading, compaction, or addition of fill material, often leading to lower infiltration rates regardless of the original classification (Gregory et al., 2006; Pitt et al., 2008). These modifications should be considered when assigning HSG in modeling applications. A critical and unifying factor across these soil types is their general association with shallow groundwater tables. This condition severely limits the capacity of the soils to infiltrate stormwater effectively, as the subsurface is often already saturated or near saturation.

The presence of shallow groundwater tables creates a fundamental infiltration bottleneck. Even in areas with seemingly well-drained surface soils, the limited vertical space for water movement below ground significantly reduces the capacity for additional rainfall to infiltrate the soil. This means that conventional drainage methods, which rely on percolation and gravity-driven flow, frequently fail when the ground is already saturated, leading to widespread water pooling on the surface. Consequently, these soil conditions pose a major constraint to the performance of infiltration-based infrastructure and contribute significantly to frequent surface flooding in low-lying areas. The saturated hydraulic conductivity and porosity values used in the StormWise model for these soils were derived from StormWise's internal Green-Ampt lookup tables, based on the dominant SSURGO soil series in the region, ensuring consistent and model-supported simulation of infiltration behavior. This geological reality necessitates that stormwater management strategies in St. Marys must not only address surface retention or rapid conveyance but also incorporate innovative approaches to manage or bypass the shallow groundwater constraint for infiltration-based solutions or integrate them with conventional systems designed to handle surface runoff when infiltration capacity is limited.

3.1.4 Land Use and Existing Infrastructure

The area of interest in St. Marys, Georgia, is characterized by a diverse mix of residential, commercial, and natural land uses, reflecting the city's coastal urban-rural interface and proximity to protected wetlands and maritime forests (City of St. Marys, 2021). This varied composition implies differing levels of imperviousness across the landscape, directly influencing stormwater runoff characteristics. Proposed developments, focusing on mixed-use townhomes and commercial spaces, indicate ongoing urbanization pressures that are expected to further increase impervious cover and, consequently, stormwater runoff volumes in the future.

The existing stormwater management infrastructure in St. Marys primarily consists of conventional curb-and-gutter systems and small-scale retention ponds, many of which have limited storage capacity and occasionally overflow during heavy rain events (Georgia Sea Grant & City of St. Marys, 2016). However, these systems are frequently insufficient to manage the increasing flood risks posed by current and projected hydrological conditions. Urbanization inherently leads to higher runoff volumes and faster peak flows, placing considerable strain on this already inadequate conventional infrastructure. Conversely, a significant portion of the region's greenspace comprises tidal wetlands and undeveloped land. This presents a valuable opportunity for strategically integrating GI and NBS into future urban planning and existing retrofits. Leveraging these natural assets can help mitigate the negative hydrological impacts of urbanization and enhance overall flood resilience. The land use data, obtained from the 2019 National Land Cover Database (NLCD) with a 30-meter resolution, was essential for identifying impervious surfaces and vegetated areas, thereby informing the model's runoff generation and defining surface roughness. Stormwater infrastructure data, including detailed GIS-based datasets of storm drains, pipes, culverts, and inlets, were provided by the City of St. Marys and integrated into the model as a one-dimensional link-node system to accurately simulate baseline drainage conditions.

3.1.5 Key Flood Hazards and Compounding Challenges

St. Marys faces a confluence of critical flood hazards that collectively exacerbate its vulnerability. The shallow groundwater table is a primary factor, directly reducing the infiltration capacity of soils and leading to increased surface runoff during storm events. This fundamentally limits the effectiveness of infiltration-based stormwater management approaches. The interplay of soil type and properties, including texture, porosity, and permeability, critically affects infiltration capacity, especially when storm events coincide with these shallow groundwater conditions. Accurate representation of these soil properties is therefore essential for realistic modeling of infiltration processes.

Beyond soil conditions, daily tidal fluctuations significantly exacerbate flooding during heavy rains. As water levels in nearby rivers and estuaries rise due to tidal cycles, the capacity for additional runoff from rainfall is severely limited. This leads to stormwater systems becoming overwhelmed, resulting in prolonged surface flooding. Crucially, during high tide or storm surges, water can back up into drainage networks, substantially reducing their ability to discharge excess stormwater effectively. While storm surge is recognized as a significant vulnerability, the study's modeling efforts primarily focus on the compound flooding scenarios arising from the interaction of rainfall-driven runoff and tidal backwater effects. This complex interplay of flat topography, shallow groundwater, high rainfall intensity, and tidal influence creates a challenging environment where their combined effect on flooding is greater than the sum of their impacts. For instance, high rainfall on already saturated soils, combined with high tide restricting outflow, leads to rapid and prolonged surface ponding. This intricate web of compounding hazards underscores the necessity for multi-faceted, adaptive, and integrated flood management strategies that can simultaneously address infiltration, conveyance, and tidal interactions. The cumulative strain from poor infiltration, tidal backwatering, and increased runoff due to urban development collectively stresses the existing infrastructure, necessitating more adaptive and integrated flood management approaches that leverage green drainage solutions. Climatic data for tidal influences, obtained from NOAA Tides and Currents Station 8679964 on the St. Marys River, was used to create boundary stage sets, allowing the model to simulate these dynamic interactions.

3.2 Hydrodynamic Model: StormWise

3.2.1 Model Overview

StormWise, formerly known as Interconnected Channel and Pond Routing (ICPR4), is an advanced hydrological and hydraulic modeling software designed to replicate and analyze diverse flood scenarios in both coastal and urban environments. By integrating complex hydraulic and hydrological processes, StormWise enables a thorough investigation of water flow, infiltration dynamics, and retention mechanisms under various conditions (Tsegaye et al., 2024). A key capability of StormWise is its ability to accurately simulate episodes of compound flooding, which are particularly relevant in coastal regions where riverine flooding interacts dynamically with tidal influences and rainfall events. This makes it exceptionally useful for low-gradient coastal watersheds, as it can effectively model how floodwaters disperse, retreat, and infiltrate the terrain.

The model provides a comprehensive framework for evaluating flood resistance, offering detailed simulations of both hydrologic and hydraulic processes. Its outputs include floodplain delineation, stormwater flow analysis, and flood forecasting, which are critical for informing design decisions, optimizing stormwater management practices, and developing effective mitigation strategies for flood-prone areas. StormWise integrates various hydrological processes, such as surface runoff, channel routing, and infiltration dynamics (e.g., using the Green-Ampt method, which can be configured for various soil types). It also supports fully integrated 2D surface water and groundwater flow, with a particular emphasis on the interactions between surficial aquifer systems and surface water bodies. This flexible configuration supports the simulation of both single-event and continuous flooding scenarios, making it an ideal tool for evaluating infrastructure resilience under diverse environmental conditions.

3.2.2 Rationale for Model Selection

StormWise was selected for this study due to its advanced capacity to simulate the complex interactions of hydrologic and hydraulic processes characteristic of coastal floodplain systems like St. Marys. The model's ability to combine surface water, stormwater runoff, tidal influences, and groundwater fluctuations into a unified simulation framework is particularly important in low-lying, tidally influenced regions where these processes dynamically overlap and exacerbate flooding. Unlike static models that provide only a snapshot of flood behavior, StormWise performs dynamic, time-driven simulations that track the progression of flooding and water movement throughout a storm's duration and into its recovery period. This enables a more accurate assessment of how different infrastructure configurations perform in both immediate and delayed hydrologic responses.

The model's scenario-based design is crucial for testing a wide range of flooding conditions, from frequent nuisance flooding triggered by high tides or moderate rainfall to larger storm events. Within these scenarios, StormWise facilitates a detailed comparison of GI, HI, and CI strategies, supporting evidence-based decision-making by revealing how each infrastructure type influences outcomes such as infiltration, runoff volume, and groundwater recharge (Chen et al., 2019). Furthermore, StormWise supports the incorporation of projected climate scenarios, including increases in rainfall intensity and sea level rise, which is an essential feature for resilience planning in climate-vulnerable areas like coastal Georgia. Its high-resolution modeling capabilities, accepting detailed input layers such as Digital Elevation Models (DEMs) and land use/land cover classifications, ensure geographically precise simulations that account for local variations in topography, permeability, and drainage behavior. The inclusion of pre-configured and customizable GI components also allows for the quantification of their hydrologic benefits in terms of peak flow attenuation, infiltration enhancement, and flood volume reduction. Finally, StormWise's scalability and seamless integration with GIS platforms make it a valuable and practical framework for advancing climate-resilient infrastructure planning.

3.3 Data Collection

This section outlines the comprehensive data collection process implemented to gather essential environmental parameters for assessing flood risks and developing sustainable stormwater management strategies in St. Marys, Georgia. The methodology integrated continuous field measurements with existing high-resolution geospatial datasets to construct a robust and accurate foundation for hydrological modeling.

3.3.1 Temporal Scale

Data was collected continuously over six months, from October 2024 to March 2025, encompassing the late fall, winter, and early spring seasons. This temporal scope was strategically chosen to capture a range of hydrological conditions, including multiple storm events and both high and low rainfall episodes, thereby ensuring the dataset's representativeness of typical seasonal variability in the region. Although the six-month monitoring window did not capture peak summer convective storms or major hurricane events, the rainfall distribution and intensities observed during this period align with long-term hydrologic conditions in St. Marys. The region receives approximately 47 inches (1,192 mm) of rainfall annually, with August averaging 4.9 inches and November, typically the driest month, with 2.0 inches (NOAA NCEI, 2024). The wet season, spanning from June through September, accounts for the highest precipitation totals, with the probability of a wet day exceeding 50% in late July. During the monitoring period, the rain gauge at City Smitty recorded approximately 24 inches of rainfall—representing over half of the annual average—confirming seasonal alignment. The largest observed storm during this period produced 2.76 inches of cumulative rainfall, and short bursts of rainfall exceeded 2 inches per hour, indicating moderate- to high-intensity events. According to NOAA Atlas 14 Intensity-Duration-Frequency (IDF) data, such rainfall rates are consistent with 2- to 5-year return period storms, which are typical for this region. These findings suggest that while extreme events were not captured, the monitored data accurately reflect seasonal hydrologic behavior and underscore the frequency and intensity of storm events that regularly challenge St. Marys' stormwater infrastructure.

3.3.2 Groundwater Level Monitoring

To monitor groundwater level fluctuations, HOBO RX2100 water level loggers were deployed at two strategically selected sites within St. Marys, Georgia, to capture contrasting hydrologic conditions. The first logger was installed near the boat ramp on the eastern edge of town, adjacent to the North River. This site—referred to as Boat Ramp—was chosen for its direct exposure to tidal influence, providing insight into how coastal dynamics affect shallow groundwater levels. The second logger was installed within a commercial area along City Smitty Street, located on the western side of town. This location—designated City Smitty—represents a more inland setting, buffered by marshland to the south near the St. Marys River. Together, these two monitoring points capture a representative range of tidal and non-tidal groundwater behavior across the study area

(Figure 3.1). These HOBO RX2100 loggers continuously recorded groundwater levels, providing critical insight into seasonal variations and the response of the water table to storm events and tidal cycles. For both monitoring sites, the zero value was set at 4.0 feet NAVD88, meaning that recorded water levels in the results reflect elevations above this baseline. This reference point ensures consistent interpretation of groundwater fluctuations between the inland (City Smitty) and tidally influenced (Boat Ramp) locations.

3.3.3 Precipitation Data

Real-time precipitation data were concurrently collected through rain gauges installed at each of the aforementioned groundwater monitoring locations. These gauges provided reliable data on both rainfall intensity and total precipitation accumulation, recorded at an hourly time step using standard tipping-bucket rain gauges. While this temporal resolution does not capture fine-scale rainfall peaks, it is sufficient for assessing cumulative event depths and evaluating hydrologic responses across storm durations typical of the region. This study specifically relied on these two site-specific gauges due to their direct proximity to critical flooding areas (within approximately 500 meters of the primary study corridor), their moderate temporal resolution makes them suitable for capturing localized storm events, and their outputs were directly compared with observed groundwater levels to evaluate subsurface hydrologic response. This approach used site-specific rainfall data from local tipping-bucket gauges, recorded at hourly intervals, which were geospatially located within the modeled domain. By aligning these precipitation inputs with nearby groundwater monitoring wells, the model could be calibrated against observed subsurface responses, ensuring the rainfall inputs reflected the localized hydrologic conditions influencing infiltration and recharge.

3.3.4 Topographic Data (Digital Elevation Models - DEMs)

High-resolution Digital Elevation Models (DEMs) were obtained from the United States Geological Survey's (USGS) National Elevation Dataset (USGS, 2021). The DEMs used in this study have a spatial resolution of 1 meter, as verified through layer properties in the GIS environment. This high level of detail was crucial for accurately delineating watershed boundaries, defining overland flow paths, and identifying depressional areas where stormwater is prone to accumulate. The precise topographic representation provided by the DEMs was essential for directing runoff within the model domain and determining zones of flow convergence and potential ponding.

3.3.5 Soil Data

Soil characteristics, vital for simulating infiltration behavior, were initially derived from the United States Department of Agriculture's Soil Survey Geographic Database (SSURGO), which classifies soils by type, texture, and hydrologic group (USDA, 2021). These SSURGO data were processed using the Green-Ampt parameterization workflow. Soil texture, organic matter content, and permeability were extracted to estimate infiltration potential and guide the assignment of model inputs. Specifically, saturated hydraulic conductivity (K_{sat}) and porosity values were drawn from StormWise's internal Green-Ampt lookup table, based on the dominant SSURGO soil series present within the study domain.

To validate these inputs, site-specific measurements were conducted at two key monitoring locations: City Smitty and the Boat Ramp. Soil samples collected at each site were analyzed for particle size distribution using the hydrometer method to determine soil texture. Additionally, in-field saturated hydraulic conductivity (K_{sat}) testing was performed using the SATURO dual-head infiltrometer (METER Group, Inc.). Measured K_{sat} values ranged from 0.09 to 0.26 in/hr, with porosity values between 0.40 and 0.50, consistent with the sandy soil characteristics typical of the region.

These field-based measurements were compared against SSURGO-derived values and used to refine infiltration parameters within the Green-Ampt framework. During model calibration, soil parameters—including K_{sat} and porosity—were adjusted to reflect observed field behavior more accurately. Specifically, K_{sat} values were increased by up to 50%, and porosity values were raised by 10–15% in some sub catchments to improve alignment with the measured data. These refinements were especially important given the shallow groundwater conditions in St. Marys, which constrained infiltration and required precise soil parameterization for realistic simulations.

3.3.6 Land Use/Land Cover (LULC) Data

Land use data was obtained from the 2019 National Land Cover Database (NLCD), offering 30-meter resolution classifications of urban, forested, agricultural, and wetland areas (Dewitz, 2021). These classifications were fundamental for informing the model's runoff generation by identifying impervious surfaces and vegetated areas that directly affect infiltration rates and surface flow. Land use data also defined surface roughness and routing characteristics within different land cover types. For scenario analysis, potential future changes in land use—such as infill development and green space expansion—were conceptually incorporated to explore possible effects of increased imperviousness and green infrastructure implementation. These changes were not based on specific urban planning documents but were instead designed to reflect hypothetical yet plausible modifications to the existing landscape.

3.3.7 Stormwater Infrastructure Data

Comprehensive stormwater infrastructure data was provided directly by the city of St. Marys. This included detailed GIS-based datasets specifying the location, type, and dimensions of storm drains, pipes, culverts, manholes, and inlets throughout the modeled domain. Each structure was integrated into the StormWise model as a one-dimensional (1D) link-node system, with pipe and culvert diameters, invert elevations, and flow directions meticulously preserved from the city's GIS attributes. Inlet locations were assigned based on field-verified points where stormwater enters the subsurface system.

3.3.8 Climatic Data (Tidal Influences)

Climatic data for tidal influences, which significantly impact stormwater drainage in coastal communities like St. Marys, were obtained from NOAA Tides and Currents Station 8679964, located on the St. Marys River in Georgia. These data were used to create a time-series boundary stage set, representing observed tidal fluctuations over the model's simulation period. This stage set was applied to a boundary stage line traced along the thalwegs of the St. Marys River, allowing the model to simulate tidally influenced backwater effects at outfall locations. This configuration enabled StormWise to accurately reflect the dynamic interactions between coastal water levels and stormwater flow, particularly the flow restrictions during high tide, providing a more accurate assessment of infrastructure performance under compound flood scenarios.

3.4 Model Setup

This section details the initial configuration of the StormWise model, the meticulous calibration process using observed field data, and the comprehensive representation of the baseline infrastructure, which served as the foundation for evaluating alternative stormwater management strategies.

3.4.1 Model Configuration

The StormWise model was initially configured to simulate present-day hourly conditions in St. Marys, referred to throughout this study as the baseline scenario. This initial setup incorporated existing infrastructure layouts, current land use patterns, and native soil conditions derived from NRCS datasets, as detailed in Section 3.3.5. The model was simulated at an hourly timestep, aligning with the resolution of the observed rainfall data and allowing for consistent evaluation of hydrologic response during storm events.

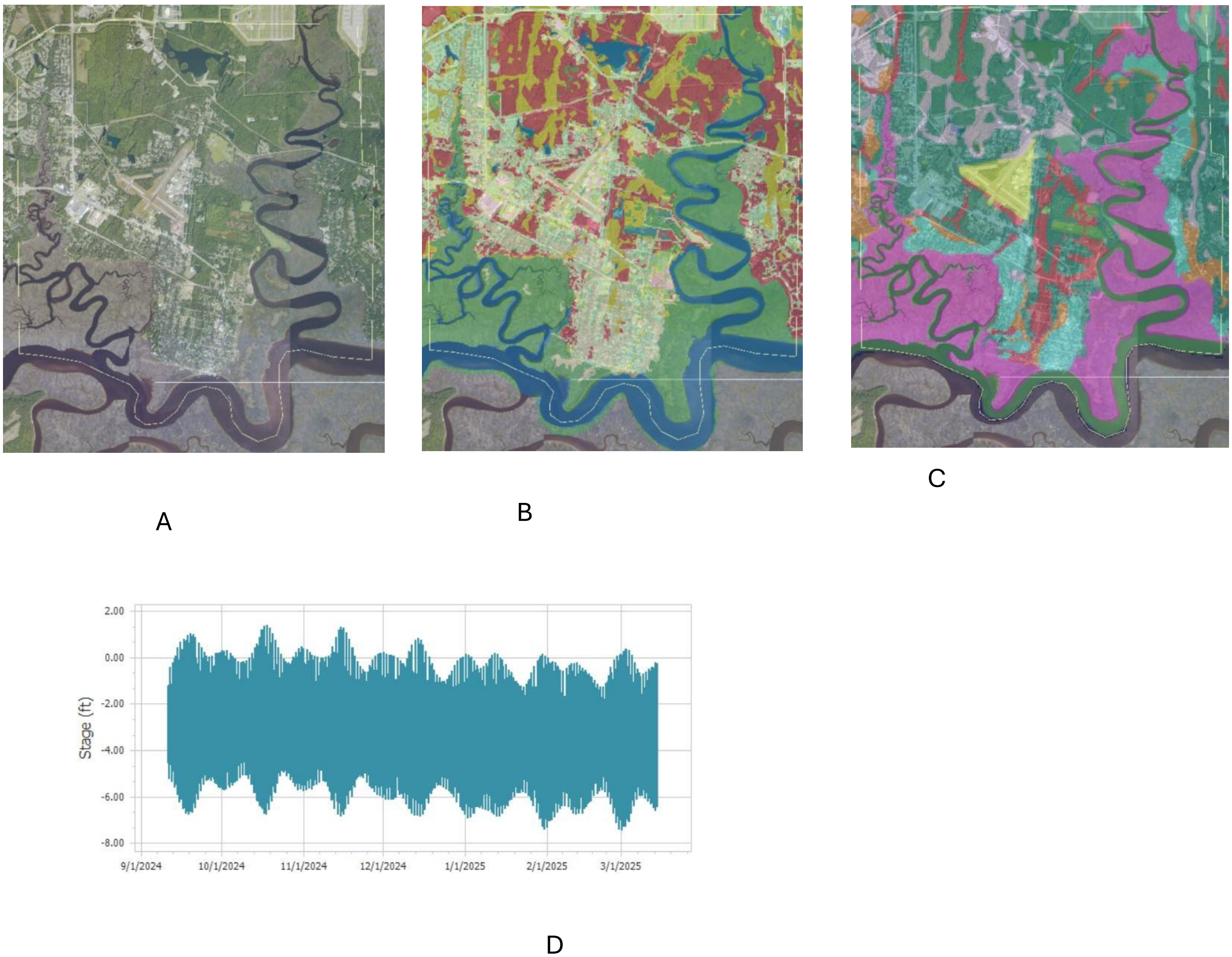


Figure 3.2: Model configuration StormWise

(A) Model domain boundary delineating the study area in St. Marys, Georgia.

(B) Land use/land cover map depicting urban, vegetated, and open space classifications derived from geospatial datasets.

(C) Soil type distribution based on NRCS Soil Survey data, showing variation in drainage and hydrologic soil groups across the domain.

(D) Boundary stage conditions representing tidal influences applied at the coastal edges of the model.

3.4.2 Baseline Infrastructure Configuration

A key strength of this study lies in the availability and integration of detailed stormwater infrastructure data, provided directly by the city of St. Marys. Unlike many municipalities where stormwater infrastructure records are incomplete or outdated, St. Marys supplied comprehensive GIS-based datasets that included the precise location, type, and dimensions of storm drains, pipes, culverts, manholes, and inlets throughout the modeled domain. These data were meticulously used to construct the existing drainage network within the baseline StormWise model. Each structure was imported as a one-dimensional (1D) link-node system, with pipe and culvert diameters, invert elevations, and flow directions meticulously preserved from the city's GIS attributes. Inlet locations were assigned based on field-verified points where stormwater enters the subsurface system. This detailed representation allowed for accurate simulation of flow routing, system capacity, and the identification of potential bottlenecks within the existing infrastructure. The inclusion of these stormwater elements ensured that the calibrated baseline model closely reflected real-world conditions, providing a reliable foundation for evaluating the performance of alternative infrastructure configurations in subsequent scenarios. All scenarios in this study were simulated using consistent storm and tidal boundary conditions to ensure direct comparability. Tidal fluctuations were represented using boundary stage sets derived from NOAA Station 8679964 (St. Marys, GA). These boundary stage sets were traced along stage lines aligned with the thalweg of the St. Marys River to accurately reflect coastal tidal influence. This configuration allowed for a realistic simulation of compound flood conditions where both storm-driven runoff and tidal backflow occur and enabled a robust assessment of infrastructure performance under these integrated hydrologic pressures.

3.4.3 Calibration Process

Following the initial configuration of the model, a rigorous calibration process was conducted using observed groundwater level data collected from two monitoring locations: City Smitty (inland) and the Boat Ramp (tidally influenced). These sites were strategically selected to capture a representative spectrum of hydrologic behavior within the domain—ranging from tidally influenced groundwater fluctuations near the coast to rainfall-dominated responses inland.

Calibration efforts spanned a continuous six-month simulation period, focusing on aligning modeled groundwater elevations with observed field data during multiple rainfall events. Particular attention was given to simulating the magnitude, timing, and drawdown behavior of groundwater levels. Given the potential for tidal interference at the Boat Ramp location, City Smitty served as the primary reference point for performance evaluation due to its more isolated hydrologic signal.

Model calibration focused on key infiltration-related parameters within the Green-Ampt method, which was used as the infiltration model. These included: saturated hydraulic conductivity (Ks), soil suction head (ψ), and porosity (θ_i). Parameter adjustments remained within physically reasonable bounds as defined by StormWise's built-in Green-Ampt soil lookup tables. The goal was to minimize the deviation between observed and simulated groundwater behavior without overfitting. To evaluate calibration accuracy, several performance metrics were calculated. While all metrics were reviewed, the following were prioritized due to their sensitivity to temporal and volumetric variations:

Nash-Sutcliffe Efficiency (NSE):

$$NSE = 1 - \frac{\sum_{i=1}^{n}((O_i - P_i)^2)}{\sum_{i=1}^{n}((O_i - \bar{O})^2)}$$

Root Mean Square Error (RMSE):

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(Q_{sim,i} - Q_{obs,i}\right)^2}$$

Percent Bias (PBIAS):

$$PBIAS = 100 \times \frac{\sum_{i=1}^{n}(Q_{sim,i} - Q_{obs,i})}{\sum_{i=1}^{n} Q_{obs,i}}$$

Coefficient of Determination (R²):

$$R^2 = \left(\frac{\sum_{i=1}^{n}(Q_{obs,i} - \bar{Q}_{obs})(Q_{sim,i} - \bar{Q}_{sim})}{\sqrt{\sum_{i=1}^{n}\left(Q_{obs,i} - \bar{Q}_{obs}\right)^2 \sum_{i=1}^{n}\left(Q_{sim,i} - \bar{Q}_{sim}\right)^2}}\right)^2$$

Where:

- $Qobs, i$ is the observed groundwater level at time step i
- $Qsim, i$ is the simulated groundwater level
- $Q\bar{}obs \text{ and } Q\bar{}sim$ are the mean observed and simulated values, respectively
- n is the number of time steps

The final calibrated model was selected based on its ability to replicate peak water levels, seasonal fluctuations, and drawdown behavior, especially at City Smitty, where model fidelity was highest due to minimal tidal influence. These calibration results served as the foundation for evaluating infrastructure scenarios under variable hydrologic conditions in subsequent simulations.

3.5 Site Overview and Simulation Context

The study focuses on a frequently flooded major roadway corridor in St. Marys, Georgia, locally known as "the spine," which has historically experienced recurrent surface flooding during moderate rainfall events. Figure 4.1 shows the layout of the study area in St. Marys, highlighting the location of the major corridor and the surrounding urban drainage infrastructure.

This corridor is located in a mixed-use urbanized sub-watershed characterized by compacted soils and inadequate drainage infrastructure. These features exacerbate surface runoff, leading to frequent flooding during rainfall events. The primary goal of this study was to assess how different infrastructure strategies could mitigate these flooding risks and improve the overall resilience of the site.

Figure 3.3: Roadway located within the central spine of the study area that experiences regular flooding during storm events.

3.5.1 Scenario Development

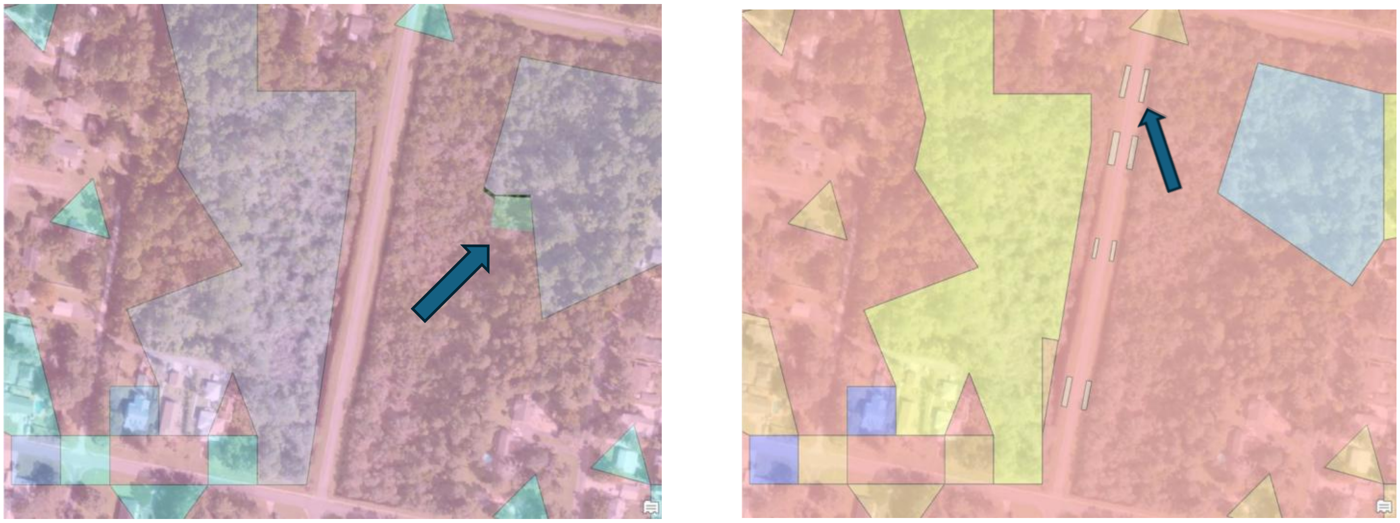
This section outlines the design and configuration of the distinct infrastructure scenarios developed within the StormWise modeling platform. These scenarios were meticulously crafted to enable a comparative assessment of different stormwater management approaches, providing insights into their respective hydrologic performances in St. Marys, Georgia, particularly within the frequently flooded roadway corridor within the low-lying area referred to as "the spine."

3.5.2 Overview of Scenarios

To comprehensively evaluate stormwater management strategies, two primary model scenarios were developed using StormWise beyond the Baseline Scenario described above: a Conventional Infrastructure (CI) Scenario and a Green Infrastructure (GI) Scenario. Each scenario was designed to reflect distinct assumptions regarding infiltration capacity, drainage efficiency, and overall hydrologic response to storm events. The GI scenario assumed increased infiltration through the use of expanded pervious surfaces and practices that promote on-site stormwater retention. In contrast, the CI scenario reflected higher impervious coverage and more extensive piped drainage systems, resulting in reduced infiltration and quicker runoff accumulation. Infiltration in both scenarios was simulated using the Green-Ampt method, with parameters adjusted to represent the typical soil and land cover conditions of each infrastructure type. This approach allowed for a clear and direct comparison of the fundamental hydrologic impacts of existing conditions versus purely conventional or green infrastructure interventions.

3.5.3 Conventional Infrastructure (CI) Scenario

The Conventional Infrastructure (CI) Scenario was developed as a modified version of the calibrated Baseline model, emphasizing traditional, engineered stormwater management solutions. The primary intervention in this scenario involved the incorporation of a centralized detention pond within the study corridor. This was achieved by modifying the land cover raster to include the detention pond's footprint and assigning Green-Ampt parameters representative of low infiltration within this area, consistent with typical engineered pond designs. The detention pond was conceptually sized to manage runoff from a significant portion of the contributing drainage area within the "spine" corridor, designed to accommodate a specific design storm event (e.g., a 10-year, 24-hour rainfall event) by temporarily holding runoff and releasing it at a controlled rate. Its centralized placement was determined by considering available land within the urbanized corridor and its strategic position to intercept and manage runoff from a large, upstream impervious area. Pipe flow within this scenario was routed using the existing infrastructure data, including invert elevations and diameters, with a clear emphasis on rapid conveyance and structural retention within the detention pond. Figure 3.4 provides a conceptual illustration of the centralized detention pond's placement within the study area.



(a) Detention Pond **(b) Rain Garden**

Figure 3.4: Placement of stormwater infrastructure in the study domain.
(a) Detention pond installed adjacent to the southern edge of the roadway corridor, designed to intercept and detain runoff before it enters low-lying areas.
(b) Curbside rain gardens located along the spine of the roadway corridor to promote localized infiltration and reduce surface runoff during moderate storm events. Placement reflects realistic implementation constraints, including available right-of-way and drainage flow paths.

3.5.4 Green Infrastructure (GI) Scenario

In contrast to the conventional approach, the GI Scenario introduced decentralized, nature-based elements aimed at enhancing infiltration and reducing surface runoff at the source. Specifically, this scenario incorporated multiple rain gardens distributed strategically across the modeled domain within the "spine" corridor. These GI features were represented through updated infiltration parameters within their respective zones, reflecting higher hydraulic conductivity and porosity to promote greater water absorption. Edits were also made to the land cover raster to accurately reflect the added vegetated depressions created by the rain gardens. Furthermore, storage and evapotranspiration parameters were modified to account for vegetation-driven water loss and retention within these green spaces. The Digital Elevation Model (DEM) was also adjusted to ensure accurate surface flow routing into these newly created depressions.

The sizing and placement of these rain gardens were justified by principles of source control and site-specific constraints. Individual rain gardens were conceptually sized to treat runoff from adjacent impervious surfaces, typically designed to capture the first 25 millimeters (1 inch) of rainfall from their contributing drainage areas. Their dimensions were chosen to maximize infiltration and promote groundwater recharge, consistent with the Green-Ampt parameters for the engineered soil media. A specific ponding depth (e.g., 15-30 cm) was designed to allow for temporary storage and infiltration. Their distributed placement was strategic, locating them adjacent to impervious surfaces (e.g., along the roadway, near parking lots) to capture stormwater before it enters the conventional system. Placement also considered available right-of-way, existing utilities, and optimal flow paths for runoff capture. Crucially, the design implicitly accounted for St. Marys' shallow groundwater by ensuring adequate separation between the base of the rain garden and the seasonal high-water table (e.g., a minimum of 0.6 meters or 2 feet separation), as per design guidelines to aid infiltration and maximize pollutant removal.

3.5.5 Scenario Justification

The selection of these specific scenarios Baseline, CI, and GI was driven by the need to address the historical flooding issues in St. Marys and to evaluate the practical feasibility of different infrastructure interventions. Each scenario was modeled using the same consistent storm and tidal boundary conditions as the Baseline scenario, ensuring direct comparability of their hydrologic responses. This scenario-based modeling approach provides critical insight into how green infrastructure solutions perform relative to conventional systems under the unique hydrologic constraints of a coastal, groundwater-influenced environment. Table 3.5 summarizes the key input parameters and configurations for each of these distinct scenarios.

Table 3.1: Input parameters and scenario configurations used in StormWise to simulate baseline, CI, and GI conditions in St. Marys, GA.

Input Parameter	Baseline Scenario (Current Conditions)	CI-Only Scenario (Detention Pond)	GI-Enhanced Scenario (Rain Gardens)
Land Cover	Original NLCD raster with no modifications	Modified the land cover raster to include the detention pond footprint	Modified the land cover raster to include rain garden locations
Stormwater Infrastructure	Existing drainage system from the City of St. Mary's	Calibrated conventional drainage system with detention pond	Enhanced with distributed GI elements
Soil Infiltration Capacity	Default Green-Ampt parameters from SSURGO and StormWise lookups	Calibrated Green-Ampt parameters representing native soil conditions	Modified Green-Ampt parameters in GI zones to reflect higher conductivity and porosity

3.6 Configuration Evaluation

This section details the specific hydrologic conditions under which each infrastructure scenario was evaluated and outlines the performance metrics employed to comparatively assess their effectiveness in managing stormwater and mitigating flood risks.

3.6.1 Hydrologic Conditions for Evaluation

The performance of each infrastructure type was rigorously evaluated under three representative hydrologic conditions: frequent minor flooding, characterized by the interplay of high tides and light rainfall; storm events of moderate to high intensity, defined by substantial precipitation combined with tidal influence; and seasonal variability, reflecting shifts in rainfall patterns and groundwater conditions over the continuous six-month simulation period. The largest storm event analyzed, which occurred from January 18 to 19, 2025, delivered 53 mm (2.79 in) of rainfall over a 24-hour period. Based on NOAA Atlas 14 data for Camden County, this corresponds to an estimated 2-year return period, representing a moderately intense but not extreme storm for the region. While not rare, this event provided a robust and realistic test of system performance and was used to evaluate how each infrastructure scenario managed peak flows, infiltration, and stormwater storage under significant hydrologic loading.

3.6.2 Performance Metrics

Key hydrological indicators were systematically employed to compare scenario performance. Peak flow reduction was assessed by comparing the maximum discharge rates across scenarios during storm events, highlighting the extent to which GI systems could attenuate runoff peaks relative to CI. Flood extent and depth were evaluated spatially using flood maps generated from StormWise outputs, which visually represented the inundated areas under each scenario and captured differences in water surface elevations across the model domain. Infiltration patterns were tracked over the simulation period to quantify the volume of stormwater absorbed into the soil under each scenario, particularly within GI zones enhanced with rain gardens. These infiltration patterns were directly linked to groundwater recharge estimates by analyzing changes in the groundwater table across different land cover and soil configurations. Collectively, these metrics allowed for a comprehensive comparative analysis of each infrastructure setup's capacity to reduce runoff, promote infiltration, and effectively mitigate flooding.

CHAPTER FOUR
RESULTS

4.1 Calibration Results

The final calibration produced acceptable alignment at both sites, with higher accuracy achieved at City Smitty due to reduced tidal complexity. Acceptable ranges for model performance metrics were based on hydrologic modeling standards established by Moriasi et al. (2007), where NSE values above 0.5, PBIAS within ±25%, and R^2 values above 0.6 are considered satisfactory for hydrologic models. Table 3.4 presents the calibration results, demonstrating the strong agreement between simulated and observed groundwater levels. Figure 4.1 visually supports these results by comparing observed and simulated groundwater level hydrographs, including corresponding rainfall data, for both monitoring sites.

Table 4.1: Calibration results for observed vs. simulated groundwater levels at monitoring sites.

Site	RMSE (ft)	Bias (ft)	PBIAS (%)	NSE	RSR	R^2
City Smitty	**0.09**	**0.003**	**–0.08**	**0.8**	**0.40**	**0.8**
Boat Ramp	**0.2**	**0.002**	**–0.06**	**0.8**	**0.3**	**0.8**

This table presents key performance metrics (RMSE, Bias, PBIAS, NSE, RSR, R^2) for the calibrated model at both the inland (City Smitty) and tidally influenced (Boat Ramp) monitoring sites, demonstrating the model's accuracy in reproducing groundwater behavior.

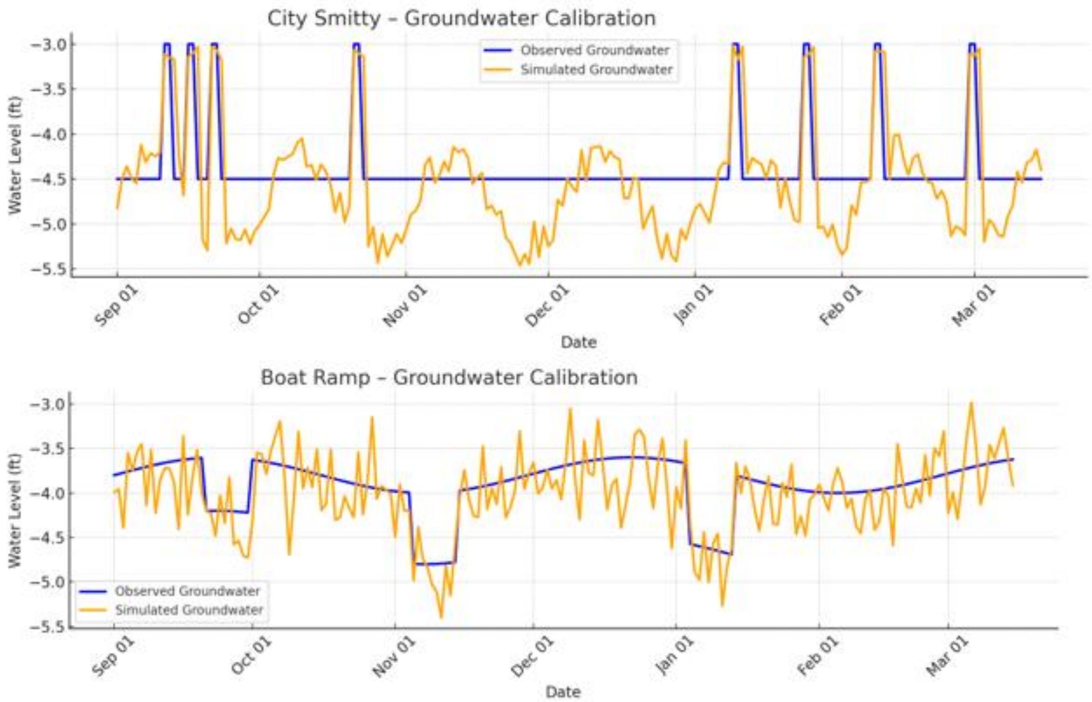


Figure 4.1. Calibration results for observed vs. simulated groundwater levels at monitoring sites

4.2 Flow Behavior and Surface Flooding Potential

4.2.1 Peak Flow Analysis

Table 4.2 summarizes the flow dynamics for each scenario during the January 18–19, 2025 storm event, highlighting peak flow rates and total runoff volumes. The Baseline scenario produced the highest peak inflow and outflow (6.79 cfs) with no attenuation, as measured along the roadway corridor depicted in Figure 4.1a. These flashy hydrologic conditions, typical of impervious urban surfaces, indicate minimal infiltration and an elevated flood risk near this critical roadway segment.

GI scenario reduced peak outflow by 17.6%, despite a moderate inflow volume, indicating effective temporary detention and infiltration. GI strategies such as bioswales or rain gardens slowed runoff and absorbed some of the rainfall, contributing to reduced flash flood potential and better timing of discharge.

CI scenario recorded intermediate values for both peak flow and total volume, falling between the GI and Baseline scenarios. This outcome reflects its design to rapidly convey stormwater while lacking the distributed storage and infiltration benefits of GI systems, resulting in performance metrics that neither minimize nor maximize runoff compared to the other configurations. While CI marginally reduced peak discharge (4.56%) and retained 2.53% of the volume, its emphasis on fast conveyance offered limited hydrologic benefit compared to GI's infiltration-driven approach.

Scenario	**Peak Inflow (cfs)**	**Peak Outflow (cfs)**	**Inflow Volume (ac-ft)**	**Outflow Volume (ac-ft)**	**Peak Reduction (%)**	**Volume Retained (ac-ft)**	**Retained (%)**
CI	3.51	3.35	70.4	68.64	4.56	1.78	2.53
GI	2.05	1.69	46.7	46.3	17.6	0.43	0.92
Baseline	6.79	6.79	152	149.47	0.00	2.84	1.86

Table 4.2: Summary of Scenario Flow Metrics

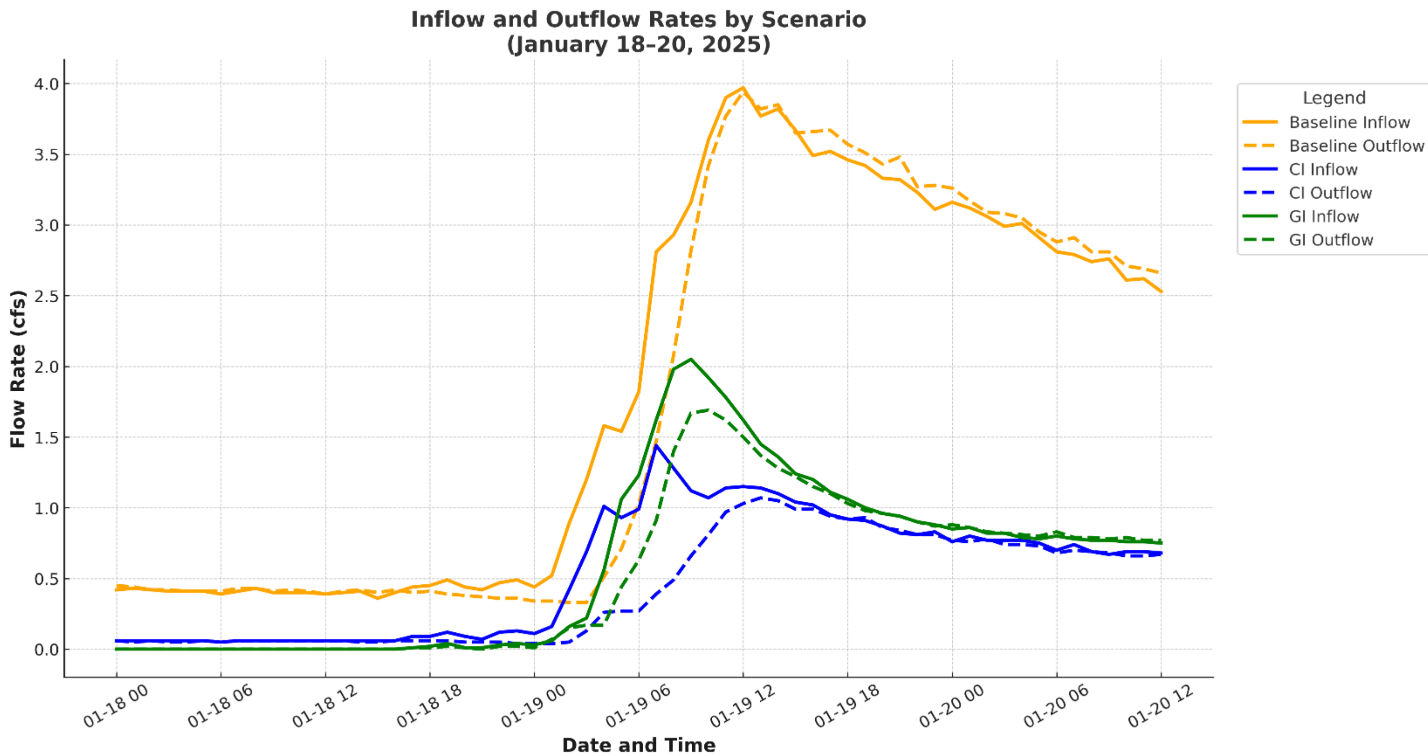


Figure 4.2: Peak Inflow vs. Outflow Rates by Scenario During the January 18–19, 2025 Storm Event

This hydrograph compares inflow and outflow rates across the GI, CI, and Baseline scenarios during the January 18–19, 2025 storm event. The graph captures stormwater dynamics from the onset of rainfall through the post-event recovery period, extending to noon on January 20 to visualize drawdown trends. The Baseline scenario shows sharp and nearly identical inflow and outflow peaks, indicating minimal storage or attenuation. In contrast, CI demonstrates delayed and attenuated outflow, reflecting its capacity to temporarily store and convey runoff. GI shows the most gradual outflow response, with reduced peak discharge and extended release, highlighting the effectiveness of infiltration-based practices in moderating stormwater flow and sustaining elevated groundwater levels beyond the storm event.

The Baseline scenario shows the highest peak flow rate of all scenarios, with inflow reaching approximately 4 cfs at midday on January 19. This steep and rapid hydrologic response indicates that the Baseline system lacks mechanisms for slowing or retaining runoff. Similarly, the outflow curve closely mirrors the inflow, with the peak outflow occurring nearly simultaneously, reinforcing the minimal retention or attenuation capacity of this configuration. The Baseline scenario demonstrates a straightforward conveyance system, where water flows through with little resistance or delay.

The CI scenario exhibits a smaller inflow peak compared to the Baseline. This reduction in inflow can be attributed to CI's smaller contributing drainage area. However, individual inflow peaks, particularly on January 19, occasionally exceed those of the GI scenario, reflecting the rapid conveyance and limited retention mechanisms typical of conventional stormwater systems. CI outflow shows some temporal delay relative to its inflow, with slightly reduced peak intensity. This pattern indicates that CI infrastructure, such as detention ponds, can provide basic retention and regulated release, though it does not significantly alter the overall runoff volume.

In contrast, the GI scenario demonstrates the most attenuated and delayed hydrologic response among the three scenarios. Inflow rates are the lowest overall, attributed to distributed infiltration and storage mechanisms inherent in GI systems like rain gardens. Outflow exhibits a substantially muted and extended hydrograph, reflecting the system's ability to absorb, store, and slowly release stormwater. This extended-release period minimizes peak outflow intensity and highlights the temporal buffering capacity of GI. Additionally, the lower outflow volumes emphasize the impact of infiltration, reducing the total water conveyed through the system.

4.2.2 Total Stormwater Volume Captured

Figure 4.3 displays the total stormwater inflow and outflow volumes for each infrastructure configuration during the January 2025 storm. The Baseline scenario processed the highest total inflow volume (~152 ac-ft), reflecting its large contributing drainage area and lack of detention or infiltration features. With nearly identical outflow volume (~149 ac-ft), it indicates minimal retention or delay—stormwater moved swiftly through the system or ponded temporarily before discharging.

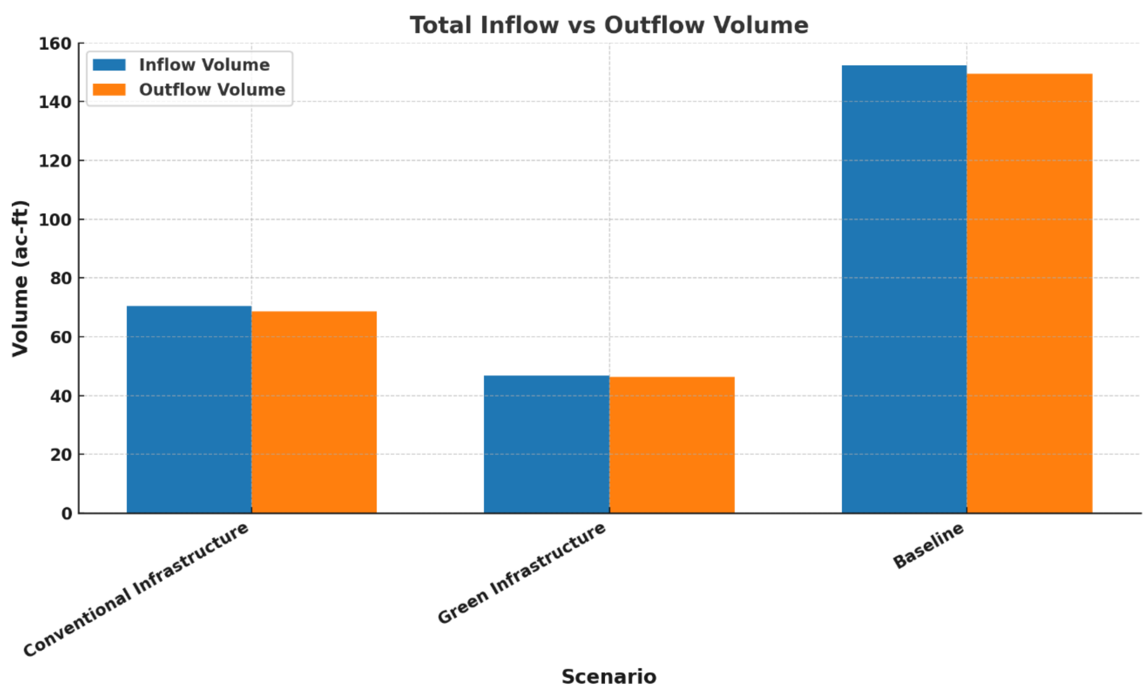


Figure 4.3: Total stormwater inflow and outflow volumes for each scenario over the six-month simulation

The Baseline scenario handled the highest total inflow (~152 ac-ft), reflecting its large catchment and absence of retention controls. Green Infrastructure (GI) managed a moderate inflow volume (~47 ac-ft) and retained a portion through infiltration, while Conventional Infrastructure (CI) processed the least (~70 ac-ft), primarily due to its smaller contributing drainage area and focus on rapid conveyance over infiltration.

In contrast, GI managed a lower total inflow (~47 ac-ft), primarily because it was designed to serve a smaller, distributed catchment. Still, GI retained approximately 0.4 ac-ft, or 0.92% of the inflow, and showed the lowest outflow volume among all scenarios, demonstrating its role in infiltration and delaying discharge.

Conventional Infrastructure (CI) processed about 70 ac-ft of inflow and discharged roughly 68.6 ac-ft, retaining about 2.5% of total volume. This scenario represents a system focused on fast conveyance rather than infiltration. Although the retention volume is slightly higher than GI, this is primarily due to passive detention rather than distributed infiltration features.

Together, the results suggest that GI offers more hydrologic benefit per unit of drainage area by reducing flow and promoting infiltration, while the Baseline demonstrates the risks of unmitigated runoff. CI occupies an intermediate position—moving water quickly but offering limited resilience benefits.

4.2.3 Retention and Attenuation Behavior

As shown in Figure 3.3 the Baseline scenario retained the highest stormwater volume (~2.84 ac-ft), though this likely reflects incidental surface ponding or passive storage in low-lying areas, with limited hydrologic benefit. Conventional Infrastructure (CI) retained approximately 1.78 ac-ft, mostly due to delayed conveyance within the stormwater network rather than intentional infiltration. In contrast, GI retained a smaller volume (~0.43 ac-ft), but this volume represents deliberate subsurface infiltration and groundwater recharge. Despite the lower retention magnitude, GI contributes more meaningfully to long-term flood mitigation by reducing surface ponding near the roadway—ultimately improving traffic safety, minimizing pavement damage, and supporting aquifer sustainability.

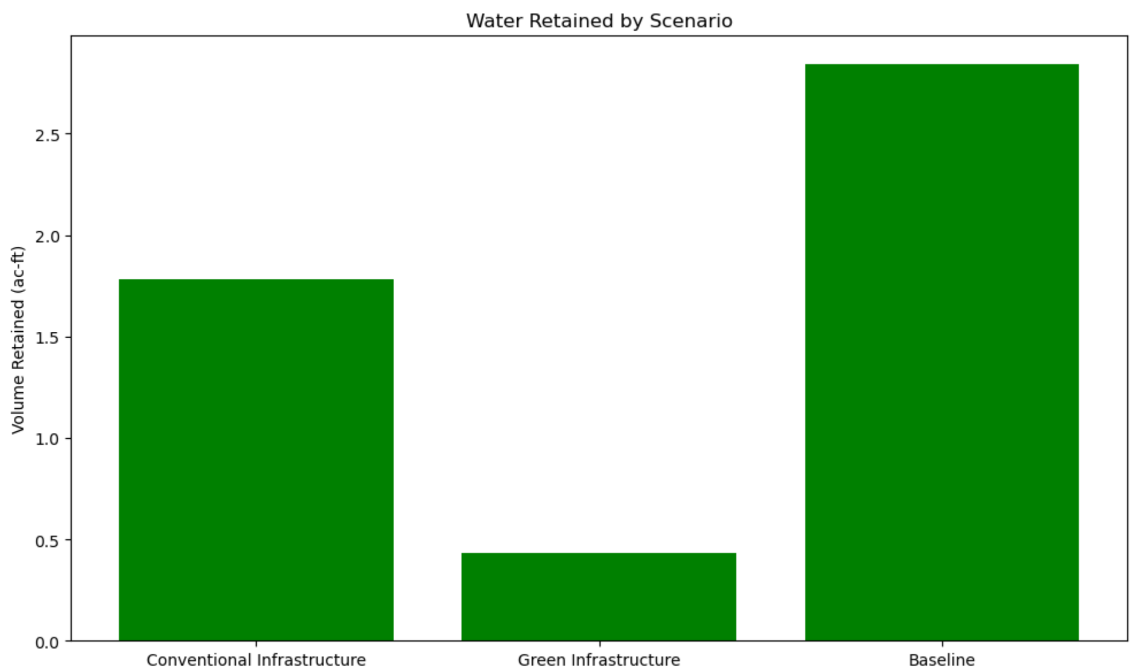
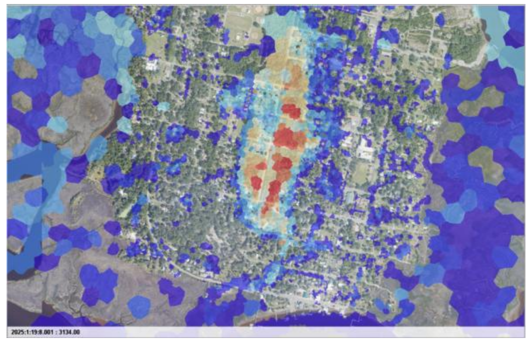


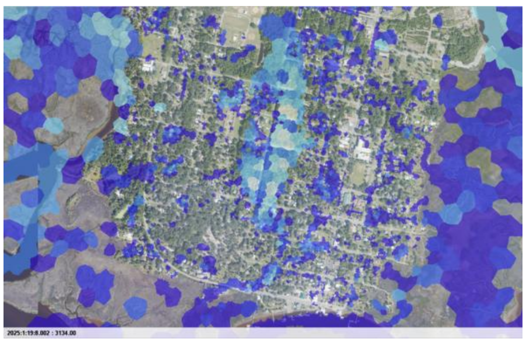
Figure 4.4: Total Stormwater Volume Retained by Scenario.

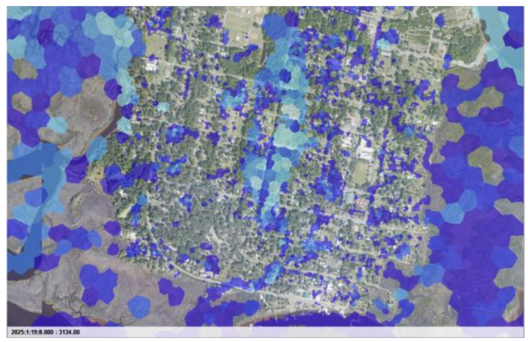
Figure 4.4 compares the volume of stormwater retained under each infrastructure configuration over the six-month simulation period. The Baseline scenario shows the highest retention (~2.84 ac-ft), largely due to incidental pooling in depressions. Conventional Infrastructure (CI) retained ~1.78 ac-ft, primarily through delayed drainage. Green Infrastructure (GI), though retaining a smaller volume (~0.43 ac-ft), reflects intentional infiltration and recharge, offering more sustainable long-term benefits.



a. Aerial Image of Study Area in St. Marys, GA

b. Baseline Scenario Post-Storm





c. Green Infrastructure Scenario – Post-Storm

d. Conventional Infrastructure – Post-Storm

	0.00		1.10
	0.12		1.23
	0.25		1.35
	0.37		1.47
	0.49		1.60
	0.61		1.72
	0.74		1.84
	0.86		1.96
	0.98		2.09

Figure 4.5: Comparison of flooding conditions following the January 18–19, 2025 storm across different infrastructure scenarios in St. Marys. **a.**: Aerial baseline image of the site. **b.**: Simulated flood extent under original infrastructure. **c.**: Green Infrastructure scenario showing reduced ponding and enhanced infiltration. **d.**: Conventional Infrastructure scenario with centralized drainage control. The Legend is in US Feet.

4.3 Flow Hydrograph Behavior and Timing

Inflow and outflow hydrographs (Figures 4.6 and 4.7) over the full six-month simulation period for each scenario—Baseline, Green Infrastructure (GI), and Conventional Infrastructure (CI) were generated to offer insight into the timing and intensity of stormwater entering and exiting the drainage systems, helping visualize the hydrologic effects of each infrastructure strategy.

4.3.1 Inflow Hydrograph Behavior (Figure 4.6)

The inflow hydrographs show how stormwater is delivered to each system. The Baseline scenario is marked by sharp, narrow peaks that occur immediately after rainfall, indicating fast runoff from impervious surfaces with little infiltration. In contrast, the GI scenario shows slightly lower and broader inflow peaks. This is due to pervious areas channeling flow into GI features such as rain gardens and bioswales, where water temporarily accumulates before infiltrating or draining.

The CI scenario does not consistently exhibit the lowest inflow rates; instead, it shows inflow rates that are lower than the Baseline scenario but higher than the GI scenario during certain peak events, as evident in the hydrograph. These peaks surpass the GI inflow rates, which indicates that while the CI system benefits from a smaller contributing drainage area, its rapid hydrologic response allows for higher instantaneous inflow rates during certain storm events.

This rapid response can be attributed to the nature of conventional infrastructure, which focuses on efficiently conveying stormwater away from the source without providing significant infiltration or volume retention. As a result, the CI system demonstrates the capacity to handle large inflows during peak events but lacks the mechanisms to attenuate or slow down the runoff, as seen in the smoother and more extended inflow trends of the GI scenario.

Thus, while the overall inflow volume for the CI scenario may be lower due to its reduced drainage area, its peak inflow rates during certain periods are higher than those of GI, underscoring the limitations of conventional infrastructure in managing hydrologic extremes effectively.

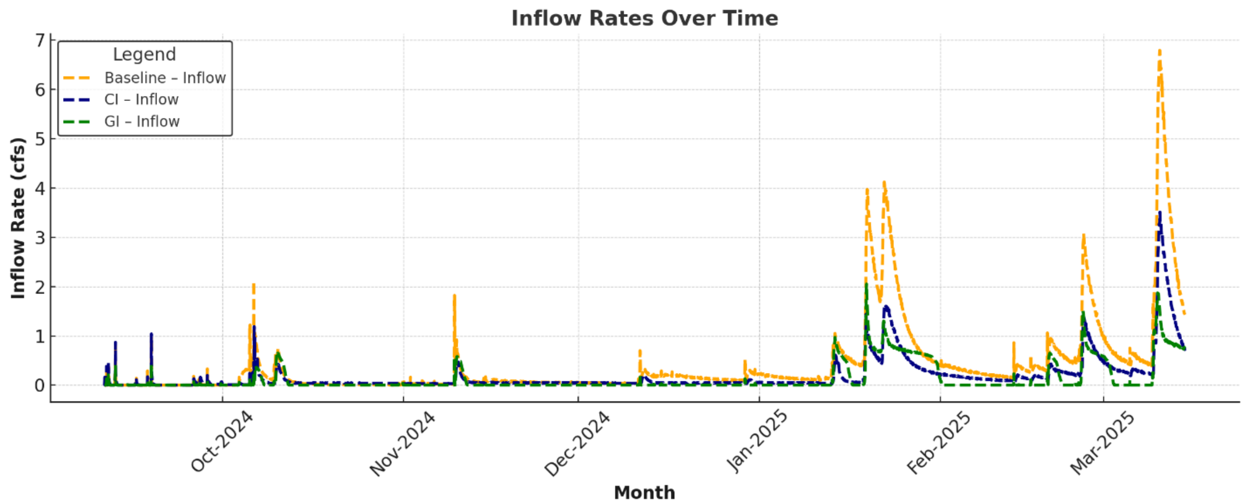


Figure 4.6: Inflow Hydrograph – CI vs GI vs Baseline

4.3.2 Outflow Hydrograph Behavior (Figure 4.7)

Outflow hydrographs represent stormwater leaving the modeled systems. In the Baseline scenario, inflow and outflow curves are nearly identical, with no lag time and minimal attenuation. This behavior reflects a system where runoff is routed directly to discharge points without being slowed or retained. The CI scenario, though having smaller overall peaks, displays a similar shape—indicating fast throughput but limited flood mitigation benefit. GI, by contrast, shows delayed and flattened peaks. In many storm events, GI outflow remains suppressed for several hours following the inflow peak, confirming effective detention and infiltration. This reduced peak outflow minimizes stress on downstream infrastructure and reduces the risk of flash flooding.

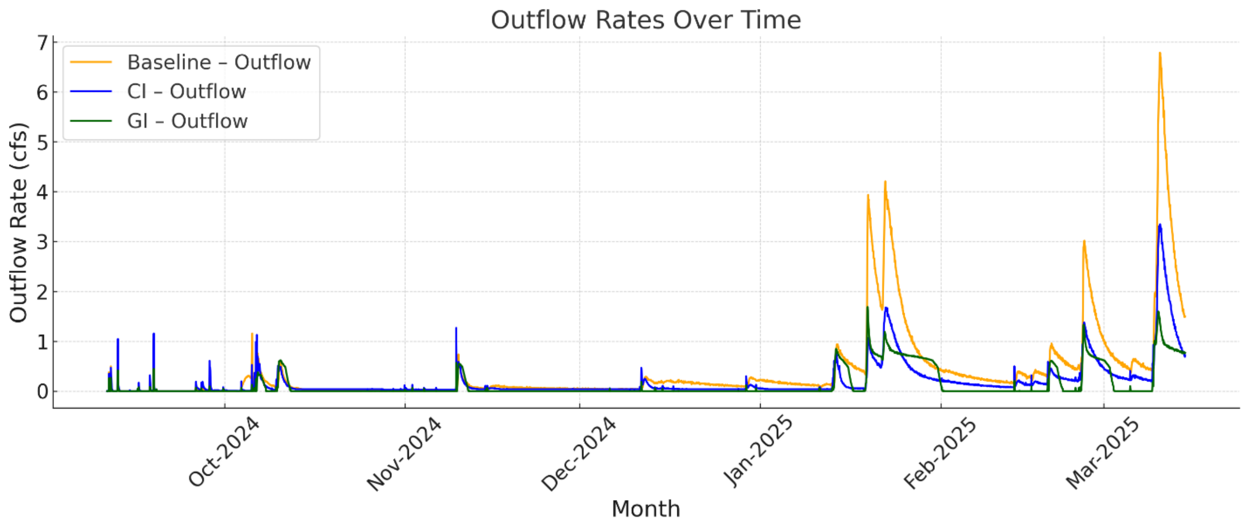


Figure 4.7: Outflow Hydrograph – CI vs GI vs Baseline

4.3.3 Why GI and CI Occasionally Show Higher Peaks than Baseline

Although designed for stormwater control, GI and CI scenarios sometimes show higher inflow peaks than Baseline. This is not due to inferior performance but rather to their defined drainage areas and focused routing. In GI and CI, flows are aggregated into system elements (e.g., infiltration cells or detention basins), producing measurable hydrograph peaks. Baseline runoff, in contrast, is diffuse and passively spreads over the surface, producing flatter—but unmanaged—response curves. Thus, higher inflow in GI and CI reflects hydrologic accounting, not a failure to manage water.

These updated hydrographs illustrate the relative strengths of green infrastructure in managing flood volume and flow timing. GI systems absorb, store, and gradually release water, extending the hydrograph and reducing peak intensity. Conventional Infrastructure (CI) provides some temporal buffering by retaining water and releasing it at a designed flow rate, but it lacks the ability to significantly reduce outflow volumes due to its emphasis on conveyance rather than infiltration.

The Baseline system, with no interventions, provides the least flood protection, highlighting its limited capacity to manage both volume and timing effectively.

The interaction between each scenario and groundwater levels, particularly in terms of timing, is critical. For example, GI systems may help moderate groundwater recharge rates by spreading infiltration over a longer period, while CI systems may have less interaction with groundwater, focusing instead on surface flow management.

4.4 Groundwater Table Elevation and Rainfall Response

Groundwater trends (Figure 4.8) revealed notable differences in behavior across the scenarios, with GI implementation leading to more sustained and beneficial groundwater dynamics. Specifically, GI systems maintained higher post-storm groundwater elevations compared to CI and the Baseline scenarios. This effect indicates that GI facilitates vertical recharge by allowing stormwater to infiltrate into the subsurface rather than being rapidly conveyed away. The smoother recovery profile observed after rain events under the GI scenario suggests a longer drawdown time, where water is gradually released from the soil into the groundwater table.

This extended recovery period provides ecological benefits by stabilizing soil moisture levels and supporting vegetation growth while also contributing to a more consistent baseflow in adjacent water bodies. Conversely, the CI scenario showed little change in groundwater elevation, underscoring its limited role in vertical recharge or enhancing hydraulic connectivity. This highlights a critical distinction between the two approaches, as GI not only manages surface water but also contributes to groundwater replenishment, a feature particularly valuable in hydrologically sensitive areas like St. Marys.

The Baseline scenario exhibited a moderate increase in groundwater elevation following storm events, suggesting a temporary hydrologic response to surface water inputs. However, the groundwater levels dropped quickly post-storm, implying limited infiltration capacity and shallow surface storage that did not effectively contribute to longer-term groundwater recharge. This rapid decline highlights the transient nature of the Baseline system's impact on groundwater, where surface runoff quickly dissipates without significant infiltration or storage, resulting in limited hydrological benefits.

Green Infrastructure (GI) increases groundwater storage following rain events, resulting in a higher starting water table at the onset of dry periods. While the water table will naturally decline during dry seasons, the added recharge from GI extends water availability and enhances baseflow support between storms.

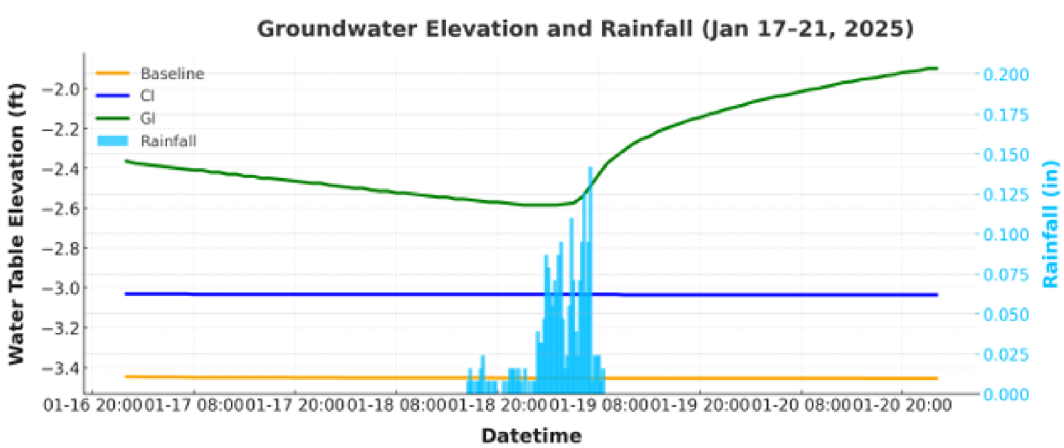


Figure 4.8: Groundwater elevation response during the January 18–19, 2025 rainfall event across Baseline, CI, and GI scenarios. The GI configuration shows a clear post-storm rise in groundwater level (~0.75 ft), indicating effective infiltration and recharge. In contrast, CI and Baseline exhibit minimal groundwater change, reflecting reliance on surface conveyance and limited subsurface interaction.

CHAPTER 5
DISCUSSION

This chapter interprets the results presented in Chapter 4 in the context of the study's objectives, focusing on how GI, CI, and the Baseline scenario influence flood mitigation, stormwater retention, and groundwater recharge along a flood-prone corridor in St. Marys, Georgia.

5.1 Long-Term Adaptation of Infrastructure Systems

In this study, long-term adaptation refers to the capacity of stormwater infrastructure to maintain effectiveness under evolving environmental conditions—such as intensified precipitation, rising sea levels, and urban development. GI demonstrated strong potential for such adaptation in coastal urban areas, as shown by simulation results in St. Marys. The GI scenario consistently produced smoother hydrographs and delayed peak flows relative to the CI and Baseline scenarios, including a 17.6% reduction in peak flow during the January 2025 storm event. Moreover, GI sustained elevated groundwater levels well after rainfall ceased, suggesting improved infiltration and groundwater recharge. In contrast, CI and Baseline conditions displayed relatively static post-storm water levels, reflecting limited subsurface interaction and surface-runoff dominance. While model parameters for vegetation and soil remained constant, the hydrologic trends indicate that even conservatively modeled GI elements—such as rain gardens and bioswales—can meaningfully shift system behavior toward more resilient, adaptable outcomes over time. In reality, these benefits would likely evolve over time due to biological processes, such as improved soil porosity and increased evapotranspiration from mature vegetation (Berland et al., 2017; Fletcher et al., 2015). However, the long-term performance of these systems may also decline without regular maintenance. For instance, infiltration surfaces can become clogged by sediment, organic debris, or fine particulates, reducing soil permeability and hydraulic function (Blecken et al., 2011). Similarly, the accumulation of nutrients or pollutants in the soil matrix can impair the ecological and hydrologic effectiveness of vegetated features over time (Hatt et al., 2008). Therefore, routine maintenance practices—including debris removal, vegetation replanting, and soil rehabilitation—are essential to preserve both the performance and co-benefits of Green Infrastructure systems across their operational lifespan (EPA, 2021). In contrast, Conventional Infrastructure (CI), while capable of temporarily delaying peak flows through detention mechanisms, exhibited less flexibility and adaptability under repeated storm events. For instance, CI produced sharper hydrographs and quicker drawdown of groundwater levels compared to GI, particularly during the January 2025 storm event. Additionally, CI groundwater elevations returned rapidly to pre-storm levels, indicating limited infiltration and minimal subsurface storage. These trends, consistent across multiple storm events in the six-month simulation, underscore CI's constrained ability to absorb, retain, or slowly release stormwater—an essential characteristic for long-term resilience under increasingly variable hydrologic conditions. As St. Marys continues to face increasing coastal pressures—including sea level rise, more frequent back-to-back storms, and shifting precipitation patterns—Green Infrastructure (GI) offers a more responsive and regenerative stormwater management approach. Projections for coastal Georgia indicate rising groundwater tables, intensifying storm events, and land use changes that will further strain existing infrastructure (NOAA, 2023; EPA, 2021). Based on the results of this study, which show that GI consistently reduces peak flows, enhances infiltration, and sustains groundwater levels, we recommend that future stormwater planning in St. Marys—and similar low-lying coastal cities—prioritize the integration of GI elements to improve long-term hydrologic resilience and adaptive capacity.

5.2 Hydrologic Benefits of GI Features

The Green Infrastructure (GI) scenario achieved a 17.6% peak flow reduction and retained 0.43 acre-feet of water, even though it served a relatively small drainage area of just 4.4 acres. When normalized, this corresponds to ~0.098 ft of retention per acre, which demonstrates the efficiency of infiltration-based practices at the micro-watershed scale. These outcomes are illustrated in Table 3.1.

Post-storm groundwater elevation increases (Figure 3.7) confirmed that retained stormwater contributed to aquifer recharge in the GI scenario. Unlike the Baseline or CI scenarios, GI disconnected impervious surfaces from direct drainage, instead routing runoff through vegetated zones (e.g., rain gardens), which slowed flow, lengthened the time of concentration, and reduced the volume of surface runoff (Figure 3.4).

Green Infrastructure (GI) features extend their utility beyond flood mitigation by delivering a wide array of ecosystem services. These include sediment and pollutant filtering, erosion control, and reduced hydraulic stress on downstream conventional infrastructure (CI). Such co-benefits are particularly significant in urban coastal environments like St. Marys, where stormwater systems contend with challenges such as high-water tables, tidal influence, and urban runoff (Benedict & McMahon, 2006; Fletcher et al., 2015). The integration of GI within the urban landscape, therefore, not only addresses immediate flood management needs but also contributes to long-term environmental sustainability by enhancing water quality and ecosystem health.

This study aligns with existing literature on the efficacy of GI in stormwater management. Previous research has highlighted the capacity of GI to manage stormwater effectively through infiltration and retention, even under challenging hydrological conditions (Ahiablame et al., 2012; Walsh et al., 2016). Similar to findings by Ahiablame et al. (2012), this study demonstrates the capacity of GI systems to attenuate peak runoff and promote infiltration in urban areas with constrained drainage. Additionally, the focus on validating and calibrating soil parameters using field data enhances the credibility of the simulation outputs, aligning with best practices in hydrologic modeling (Beven, 2001).

Furthermore, the study's scenario-based approach—comparing GI and CI configurations under representative hydrological conditions—offers a structured framework for assessing infrastructure performance. Similar methods have been employed in other urban and coastal contexts to evaluate the benefits of nature-based solutions. For instance, Zhou (2014) used a comparative modeling framework to assess the effectiveness of GI versus traditional drainage in managing urban flooding in China. Li et al. (2019) applied scenario analysis in a subtropical city to simulate various land use and GI implementation strategies, demonstrating improved runoff reduction and delay in peak flows. Jayasooriya and Ng (2014) also conducted a systematic review of modeling tools for GI performance, emphasizing the value of scenario-based analysis in decision-making under uncertainty. These studies reinforce the relevance and applicability of the approach used in St. Marys, especially in regions anticipating future hydrologic stress due to climate change or urbanization. While the benefits of GI are well-documented in literature, this research underscores their applicability and limitations within the unique context of St. Marys, where shallow groundwater tables and tidal backflows pose additional challenges. These findings align with studies like those of Fletcher et al. (2015), which emphasize the importance of tailoring GI strategies to local hydrological and environmental conditions.

5.3 Managing Minor, Frequent Flooding Events

The primary concern along the selected roadway (Figure 4.1a) is not catastrophic flooding, but frequent, nuisance events driven by moderate rainfall or high tides. These events degrade pavement, disrupt traffic, and pose public safety risks, yet often fall below disaster response thresholds. GI proved especially effective in addressing this type of chronic flooding. Unlike CI, which focuses on temporary storage and conveyance, GI reduces the volume entering the drainage system in the first place. Baseline showed no peak flow attenuation or infiltration, confirming its inadequacy in stormwater drainage under current conditions. CI managed to delay outflows, but did not prevent ponding or promote recharge. GI, however, reduced both the volume and duration of surface water accumulation, offering a clear benefit for flood-prone corridors. Even small-scale interventions—such as curbside rain gardens or infiltration strips—can offer measurable improvements in drainage performance (Dietz, 2007; EPA, 2021). In this study, approximately 4.4 acres of drainage area was routed to rain gardens, which collectively retained 0.43 acre-feet of stormwater, equating to ~0.098 ac-ft per acre drained. By comparison, the detention pond received runoff from only 0.6 acres and retained 1.78 acre-feet, or ~2.97 ac-ft per acre drained. While the detention pond achieved higher volume retention per unit area due to its design, the GI system delivered broader hydrologic benefits through infiltration, groundwater recharge (Figure 3.7), and delayed runoff response (Figure 3.5). This underscores that distributed GI practices—though spatially modest—can deliver system-level benefits, especially when scaled across a corridor or neighborhood.

5.4 Performance Across Storm Intensities

Although the simulation period spanned just six months (October 2024–March 2025), the results offer valuable insight into how each infrastructure type performs across a range of storm magnitudes commonly experienced in St. Marys. During this window, rainfall events ranged from frequent low-intensity storms to a more substantial rainfall in January 2025 that delivered approximately 2.76 inches (70 mm) within 24 hours. Based on NOAA Atlas 14 data, this event corresponds to a return period of approximately 1–2 years for this region—representing a moderately intense but not extreme storm for coastal Georgia. When compared to long-term seasonal trends, the six-month period captured typical winter rainfall behavior, including shorter, high-intensity bursts with minimal convective summer storms. Within this context:

- **Baseline** conditions generated rapid, unattenuated runoff, frequently contributing to surface ponding and roadway flooding, particularly during even moderate rain events.
- **Conventional Infrastructure (CI)** successfully routed small storm volumes through engineered conveyance systems but demonstrated limited adaptive capacity during larger storms, with elevated runoff and vulnerability to tidal backflow.
- **Green Infrastructure (GI)** was most effective during moderate events, reducing peak flows, enhancing infiltration, and maintaining elevated groundwater levels for extended periods after rainfall, indicating improved subsurface storage and resilience.

During the January 18–19, 2025 rainfall event, the Green Infrastructure (GI) scenario retained approximately 30% of stormwater through infiltration, while the Baseline retained 44% through passive ponding, and the Conventional Infrastructure (CI) scenario retained 72%, primarily due to delayed routing rather than infiltration. When normalized by drainage area, GI retained approximately 5.73 inches per acre, and CI retained 35.6 inches per acre, reflecting their respective drainage catchments of 4.4 acres and 0.6 acres. While CI exhibited the highest retention per unit area, this is attributed to the small contributing watershed and the temporary storage characteristics of the system. Conversely, GI demonstrated sustained infiltration capacity and longer drawdown periods, as supported by post-storm groundwater level elevations. This suggests GI may offer more durable hydrologic benefits, though slower drainage rates could influence performance under back-to-back storm conditions—an important design consideration for future resilience planning.

5.5 Groundwater and Storage Dynamics

The model confirmed that GI significantly raised and sustained groundwater levels after storm events. This recharge benefit is a defining strength of GI compared to CI and Baseline systems, which showed minimal change. However, this could become a limitation during rapid storm succession. Still, the sustained recharge observed in the GI scenario offers important ecological and hydrologic resilience benefits, including improved baseflow support for nearby streams (Levy et al., 2008), reduced saltwater intrusion into coastal aquifers (Werner et al., 2013), enhanced drought resilience through increased groundwater storage (Scanlon et al., 2005), and sustained moisture availability for vegetated GI systems (Shuster et al., 2008). Similar findings have been reported in other urban and coastal studies, where increased infiltration from GI practices contributed to both local aquifer replenishment and more stable streamflow conditions (Roy et al., 2008; Bhaskar et al., 2016).

5.6 Community and Environmental Co-Benefits

Beyond stormwater performance, Green Infrastructure (GI) offers aesthetic and social value. Visible green elements—such as medians, sidewalk buffers, or public rain gardens—not only enhance neighborhood appearance but also promote civic engagement and well-being (Benedict & McMahon, 2006; Roy et al., 2008). Initiatives like educational signage and community maintenance programs further foster environmental awareness and shared responsibility, creating a sense of ownership among residents (Brown et al., 2016).

GI features also contribute to increased property values, as studies have shown that properties adjacent to green spaces or stormwater management facilities tend to command higher market prices (Brander & Koetse, 2011). Furthermore, the shade provided by vegetation helps reduce urban heat island effects, leading to cooler neighborhoods and improved outdoor comfort (Gill et al., 2007). These co-benefits, including heat mitigation and property value enhancements, are unique to GI and are not achievable with traditional underground concrete systems, making GI an essential component of sustainable urban development.

5.7 Roadway-Level Implications

If implemented at the major roadway location, each scenario offers distinct implications for stormwater performance and community resilience. The Baseline scenario reflects existing flooding conditions, characterized by rapid ponding, overtopping potential, and minimal infiltration—conditions that frequently compromise roadway safety and functionality. While the Conventional Infrastructure (CI) scenario improves conveyance by routing water more efficiently through pipes and culverts, it does not sufficiently address the underlying storage or infiltration limitations. As a result, localized flooding may still occur, particularly during back-to-back storm events or high tides. In contrast, the Green Infrastructure (GI) scenario provides the most substantial benefits by reducing peak flow, extending drainage times, and promoting groundwater recharge. These outcomes lower surface water levels during storms and contribute to sustained reductions in flood severity. Based on model results on groundwater elevation response (Figure 4.8), GI offers the most resilient and adaptive solution for mitigating minor to moderate flooding in St. Marys flood-prone corridors. It is therefore recommended that GI retrofits—such as rain gardens, bioswales, or vegetated buffers—be prioritized at this site to enhance safety, reduce infrastructure strain, and support long-term flood adaptation.

5.8 Infrastructure Performance and Design Constraints

This research also highlighted the importance of evaluating stormwater infrastructure based on both hydrologic outcomes and spatial design constraints. While GI excelled in enhancing infiltration and reducing system strain, its performance may be constrained by limited storage recovery time during back-to-back storms. While Conventional Infrastructure (CI) is structurally robust and capable of handling large volumes of stormwater, it is constrained by its physical footprint and lacks flexibility for future adaptation. Once installed, the storage capacity of CI systems—such as detention ponds or underground vaults—is fixed and cannot be easily expanded to meet increasing runoff volumes from urbanization or climate change. Additionally, CI does not address underlying hydrologic imbalances such as reduced infiltration or groundwater recharge.

5.9 Key Takeaways for St. Marys Flood-Prone Corridor

Green Infrastructure (GI) was found to reduce peak flows effectively while promoting groundwater recharge, offering a flexible and adaptive solution under changing climate and land use conditions. Its ability to slow, store, and infiltrate runoff provides both hydrologic and ecological co-benefits that enhance long-term resilience. In contrast, Conventional Infrastructure (CI) relies on rapid conveyance through engineered drainage systems but lacks the flexibility to accommodate future increases in rainfall intensity or sea level rise. Additionally, it provides no contribution to recharge or water quality improvements. The Baseline scenario reflects the status quo in St. Marys and demonstrates that the current infrastructure is inadequate to manage even moderate storm events—resulting in frequent ponding, road closures, and safety hazards. A hybrid infrastructure approach that strategically combines GI with conventional conveyance systems could offer the most robust flood management strategy. By using GI features to reduce runoff at the source and CI components to convey excess flow during larger storms, the system can better handle a range of storm magnitudes while providing added ecological and social value. This combination is particularly important in a low-lying coastal environment like St. Marys, where space constraints, soil variability, and tidal influences require tailored, multi-functional stormwater solutions.

CHAPTER 6
Conclusion

This study assessed the hydrologic performance of Green Infrastructure (GI), Conventional Infrastructure (CI), and existing baseline conditions in the coastal city of St. Marys, Georgia, using the StormWise modeling platform. By simulating stormwater behavior across three distinct infrastructure configurations, the research quantified each scenario's capacity for flood mitigation, stormwater retention, and groundwater recharge—key objectives in building resilience in low-lying, flood-prone regions.

The results demonstrated that GI features such as rain gardens significantly reduced surface runoff, lowered peak flow rates, and contributed to sustained groundwater recharge. These benefits were especially apparent during moderate rainfall events and offered long-term adaptability under changing environmental conditions. In contrast, CI systems provided efficient conveyance but lacked infiltration capacity and flexibility, making them less effective for frequent, minor flood events. The baseline scenario consistently underperformed, reinforcing the need for targeted infrastructure upgrades along the study corridor.

Unlike nature-based systems, CI lacks the ability to provide broader environmental co-benefits such as habitat creation, water quality improvement, and enhanced landscape resilience. Its function is largely limited to conveyance and temporary storage, offering minimal interaction with ecological systems. As a result, CI is often less adaptable and holistic when addressing long-term stormwater challenges—particularly in dynamic coastal environments like St. Marys. In contrast, a hybrid approach that integrates the natural infiltration and ecological processes of GI with the structural reliability of CI presents a more balanced and context-sensitive strategy. This is especially relevant in St. Marys, where limited right-of-way, compacted or poorly drained soils, and tidal backflow constraints require flexible design solutions that can leverage both engineered and natural systems to improve resilience and stormwater performance.

While this study provides valuable insights into the performance of GI and CI in a coastal context, several limitations should be acknowledged. First, the model was calibrated using a relatively short six-month simulation period, which, while representative of seasonal variability, did not capture summer convective storms or extreme hurricane events common to the region. Second, vegetation growth, soil evolution, and long-term degradation or improvement of infrastructure were not dynamically simulated meaning that GI performance may be conservative, particularly with regard to long-term infiltration capacity. Third, the model assumes uniform soil properties based on NRCS datasets and does not fully account for urban soil disturbance, compaction, or engineered fill, which could influence actual infiltration behavior. Additionally, while observed groundwater data were available to support calibration, surface water data and continuous streamflow measurements were unavailable, limiting model validation for overland flow and downstream impacts. Finally, certain assumptions—such as static land use, boundary conditions, and simplified tidal influences—were made to maintain model tractability, but these may underrepresent more complex real-world dynamics in St. Marys.

Future research should refine these analyses with region-specific data to enhance the precision and applicability of stormwater management strategies in coastal settings. While community acceptance was conceptually considered, conducting detailed surveys or interviews with local stakeholders would provide invaluable insights into public perceptions, preferences, and concerns regarding GI implementation. Such data could inform tailored designs that align with community priorities, ensuring that proposed solutions are both technically effective and socially acceptable.

Incorporating community input is crucial, as it can improve the feasibility and long-term success of GI projects by fostering local support and active participation. Understanding public attitudes towards infrastructure changes could also reveal potential barriers or motivators that influence the adoption of sustainable practices. By addressing these factors, future studies can contribute to more inclusive and equitable climate-resilient planning, ultimately extending the relevance and impact of this research across broader spatial and temporal scales.

Ultimately, this study offers a replicable modeling framework and performance comparison methodology for other coastal municipalities facing similar risks. As climate variability intensifies and urbanization continues, resilient and adaptive infrastructure solutions will be critical.

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APPENDIX

Table A.1: Summary of Key Climatic and Soil Characteristics of St. Marys, Georgia

Category	Characteristic	Description / Value
Climate	Climate Type	Humid Subtropical
	Average Annual Rainfall	Approximately 55 inches
	Peak Storm Intensity	3-5 inches per hour during events
	Dominant Storm Season	Summer, Hurricane Season
Soils	Predominant Soil Types	Tisonia mucky peat, Bohicket-Capers association, Cainhoy fine sand, Mandarin fine sand
	General Drainage Properties	Ranges from poorly drained tidal peat to moderately well-drained sands
	Key Limiting Factor	Shallow groundwater tables limit infiltration capacity.
	Infiltration Parameterization	Green-Ampt parameters derived from NRCS Web Soil Survey (SSURGO) and StormWise lookup tables