Determining Implementation Barriers for Green Infrastructure for Coastal Flood Control

Stormwater Modeling Report

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1 Introduction

1.1 Background

Green stormwater infrastructure (GSI) is a term for a range of stormwater management systems that use natural processes to capture, slow down, and filter stormwater runoff (see an example in Figure 1 (EPA 2018)). GSI is often an engineered system, that is, it is designed and built based on formulas derived from science applied to urban and rainfall conditions. GSI reduces the volume and improves the quality of the runoff, thereby preventing downstream flooding and environmental damage. Thus, municipal stormwater ordinances that call for GSI address two goals significant with respect to federal law and policy: improving a community's score under the Federal Emergency Management (FEMA) Community Rating System (CRS) program to reduce impacts from flooding, and satisfying requirements under the federal Clean Water Act to reduce pollution.

Figure 1. A bioretention cell as an example of green infrastructure in which stormwater runoff enters and infiltrates into the ground through the amended soil rather than into a storm drain. (Source: EPA, 2018)

Despite the environmental and health benefits of GSI, there are often significant barriers to implementing these resilience practices. In 2011, the Clean Water America Alliance identified four categories of barriers that often prevent the adoption of green infrastructure: (1) technical and physical; (2) legal and regulatory; (3) financial; and (4) communities and institutional (Abhold, 2011). For example, local rules and regulations may be lacking or strict, and funding may be limited. A 2015 poll found that the greatest challenge facing the stormwater sector was financing (36%), with developing realistic permit criteria that drive actual water quality improvements being a close third (23%), behind engaging the public and conveying the value of stormwater management (24%) (Water Environment Federation, 2015). The concept of flood resilience blends and balances all of these ideas.

1.2 Research Project

The Mississippi-Alabama Sea Grant Consortium (U.S. Department of Commerce's National Oceanic and Atmospheric Administration under NOAA Award NA18OAR4170080) has issued a grant to University of Mississippi researchers to analyze technical, financial, and legal barriers to implementing green stormwater infrastructure (GSI). The research has been conducted in partnership with two coastal municipalities, Biloxi, MS and Orange Beach, AL. Study sites were selected from each city, and the analysis was conducted using the site plans as sample development designs. This research aims to help coastal cities become more resilient to flooding by improving their stormwater management practices. Including GSI as part of the stormwater management systems can control flooding and meet the stormwater ordinance requirements (Kousky et al. 2013). Bioretention, rain gardens, permeable pavements, and rain barrels are some examples of GSI. Specific barriers to the implementation of GSI identified for this project are: lack of track records on the performance of GSI; higher costs related to the construction and maintenance and operation (O&M) of GSI; and that city ordinances do not require GSI (CWAA 2016; Dhakal and Chevalier 2017). While GSI can also improve water quality, that assessment is outside the scope of this project.

The performance of GSI in runoff reduction was assessed for different types of practices using a study site from each city, the La Quinta Inn in Biloxi and the Robinson Grove housing development in Orange Beach. The analysis was done by performing rainfall-runoff analysis with several GSI options combined with traditional stormwater control practices. The results for the GSI performance analysis are presented in this report.

2 Objectives

The ultimate goal of this report is for cities in the Northern Gulf of Mexico to be able to use the results of these analyses to address stormwater runoff from projects in their areas. Northern Gulf communities typically have similar soil types and rainfall amounts, making this data directly on point. The research assessed both residential and commercial developments, which typically have different zoning requirements regarding impermeable surfaces and landscaping. This gives other cities the opportunity to compare prospective sites in their communities to the sites analyzed in this project, and to make changes by adding green stormwater infrastructure. For example, zoning codes require a certain percentage of landscaping (or pervious areas), more in residential areas, less in commercial. But all landscaping could be made into a tool to reduce stormwater runoff, and this report demonstrates how.

This specific report will address the following four objectives.

Objective 1: Estimate changes in potential floodwater volumes based on different stormwater control structures according to city requirements.

Objective 2: Estimate construction and long-term O&M costs for stormwater infrastructure, including GSI options.

Objective 3: Determine at what point city requirements for GSI and life-cycle costs balance.

Objective 4: Modify ordinances to include flexible GSI options for coastal communities to improve their resilience to flooding.

In this report, the outputs from Objective 1, stormwater modeling, will be reported.

3 Study Areas

The sites analyzed for this project were the La Quinta Inn in Biloxi, MS and Robinson Grove in Orange Beach, AL. The analyses of these sites can be used as examples of how sites can be analyzed anywhere in the Northern Gulf of Mexico states.

The La Quinta site is located on Cedar Lake Road in Biloxi, MS (Figure 2a). The hotel was built before the current stormwater ordinances and includes a three-story building, associated parking lots, a swimming pool, and a driveway. The building covers 21,460 ft^2, the paved parking and access area cover 36,359 ft^2, the pool covers 730 ft^2, and the landscaped area is 23,803 ft^2. The total area of this development is 82,252 ft^2. A privately-owned retention wet pond is located outside of the property to the west and receives runoff from the surrounding area, including the hotel.

The Robinson Grove housing development site is a proposed development (being built at the time of this writing) located in Orange Beach, a coastal city in Alabama. The site is located on Walker Key Boulevard. The development includes fourteen freestanding townhouses with parking spaces underneath, a driveway, landscaping, and a swimming pool. The total area of this development is 73,487 ft^2 (Figure 2b). The houses will cover 14,898 ft^2, the paved surfaces will cover 21,813 ft^2, the pool will cover 730 ft^2, and the landscape area will cover 25,657 ft^2.

(a) (b)

Figure 2. The study sites (a) La Quinta Inn, Biloxi, MS and (b) Robinson Grove, Orange Beach, AL

4 Methods

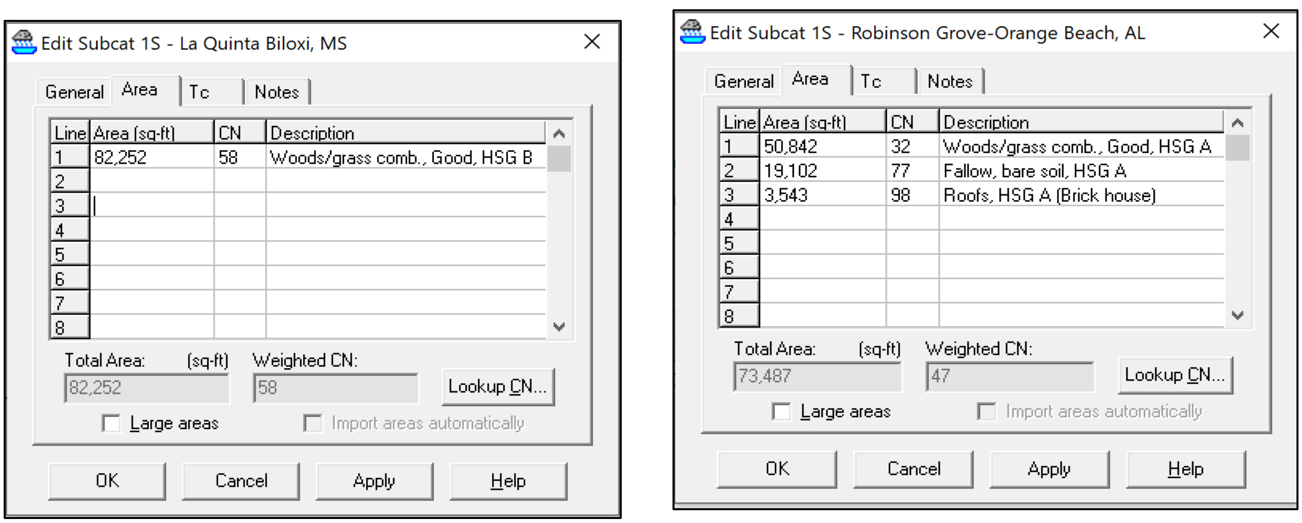
4.1 HydroCAD Model and Scenarios for Stormwater Volume and Peak Flow Estimation

To meet Objective 1, the HydroCAD software was used to simulate rainfall-runoff relationships for the two sites for three scenarios: (1) pre-development, (2) post-development with no stormwater collection, and (3) post-development with traditional stormwater detention and GSI settings. The National Resources Conservation Service (NRCS) curve number (CN) method was followed for all of the models, in which the CN was the main factor affecting runoff volumes. The runoff volume and peak flow were estimated using each city's design storm as found in its respective ordinance. Table 1 shows the rainfall depths for the cities' design storms (City of Biloxi 2021; City of Orange Beach 2020).

Table 1. Design storm depths

City	Return Period	Design storm magnitude (in/24-hr)	Major Hydrologic Soil Group
Biloxi, MS	100 years	14.5	B
Orange Beach, AL	25 years	11.8	A

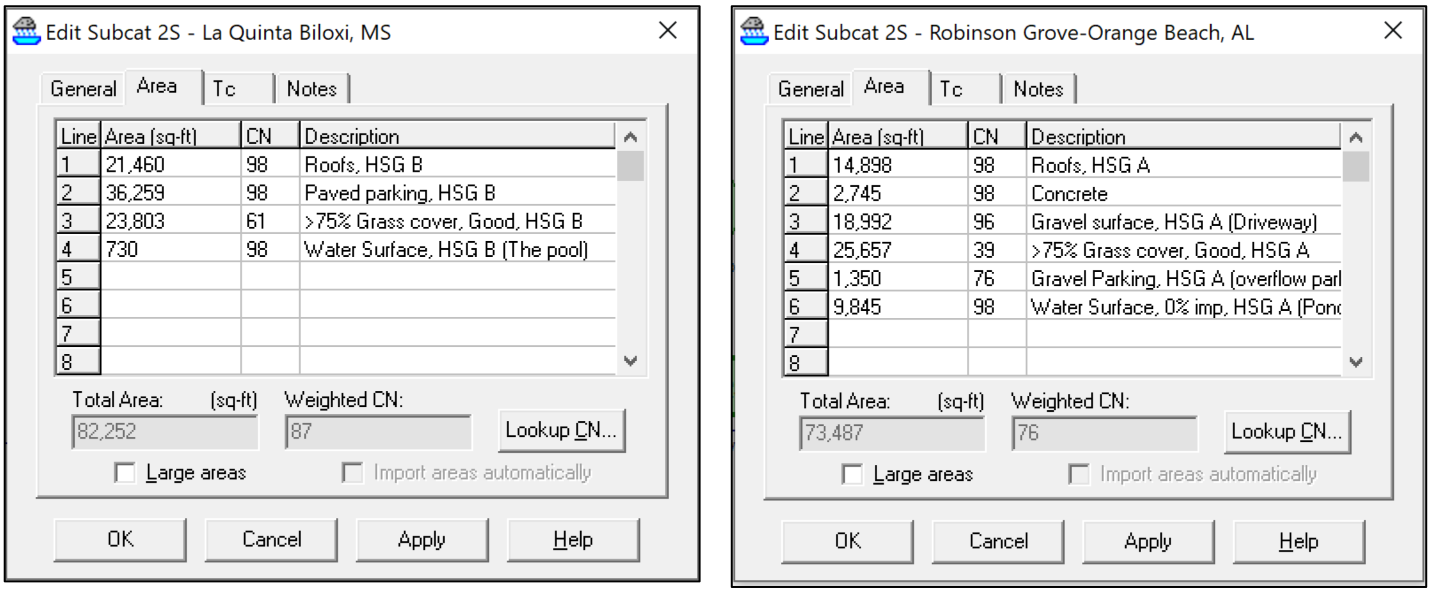
The pre-development models were performed using the land cover of the sites before construction. Figure 2 shows the input screen of HydroCAD for the land cover and the CN of the pre-development scenario of each site.



(a) (b)

Figure 2. HydroCAD screenshots of pre-development land cover of the sites (a) La Quinta Inn, Biloxi, MS; (b) Robinson Grove, Orange Beach, AL

The post-development model was performed for the developed condition of the sites, which includes rooftops, parking lots, and landscaped areas. The developed condition of the sites resulted in more impervious surfaces than the pre-development condition. During the pre-development rainfall-runoff analysis, the weighted CN for the La Quinta site was 58, and for the Robinson Grove site, it was 47 (Figure 2). The post-development weighted CN increased to 87 and 76 for La Quinta and Robinson Grove, respectively, because of the added impervious surfaces. Figure 3 shows the HydroCAD screenshots of the land cover and the corresponding CN of the post-development scenarios of the sites.



(a) (b)

Figure 3. Post-development land cover of the sites (a) La Quinta Inn, Biloxi, MS, (b) Robinson Grove, Orange Beach, AL

Both cities's ordinances require the post-development runoff peak flow leaving the site to be at or below the pre-development runoff peak. The sites were modeled for the pre- and post-development (without stormwater infrastructure) scenarios to determine the difference in the amount of runoff due to the development. Then, to maintain the peak flow requirements and determine how much volume and peak flow could be reduced with GSI, the sites were modeled with different GSI options (scenarios). The different scenarios were simulated by adjusting the CN values and routing the runoff through the GSI to an outlet structure. The specific GSI proposed for the sites consisted of permeable pavements, rain gardens, and grassy ditches. A CN adjustment was used for the permeable pavements, and the runoff route method was used for the rain gardens and grassy ditches.

For the La Quinta site, a total of four scenarios were considered with different GSI options, as shown in Figure 4.

Scenario 0 - Baseline scenario with traditional storage (the retention pond)
Scenario 1 - Permeable concrete parking spaces
Scenario 2 - Rain gardens in the parking island
Scenario 3 - Grassy ditch on the north side of the site
Scenario 4 - A combination of Scenarios 0-3

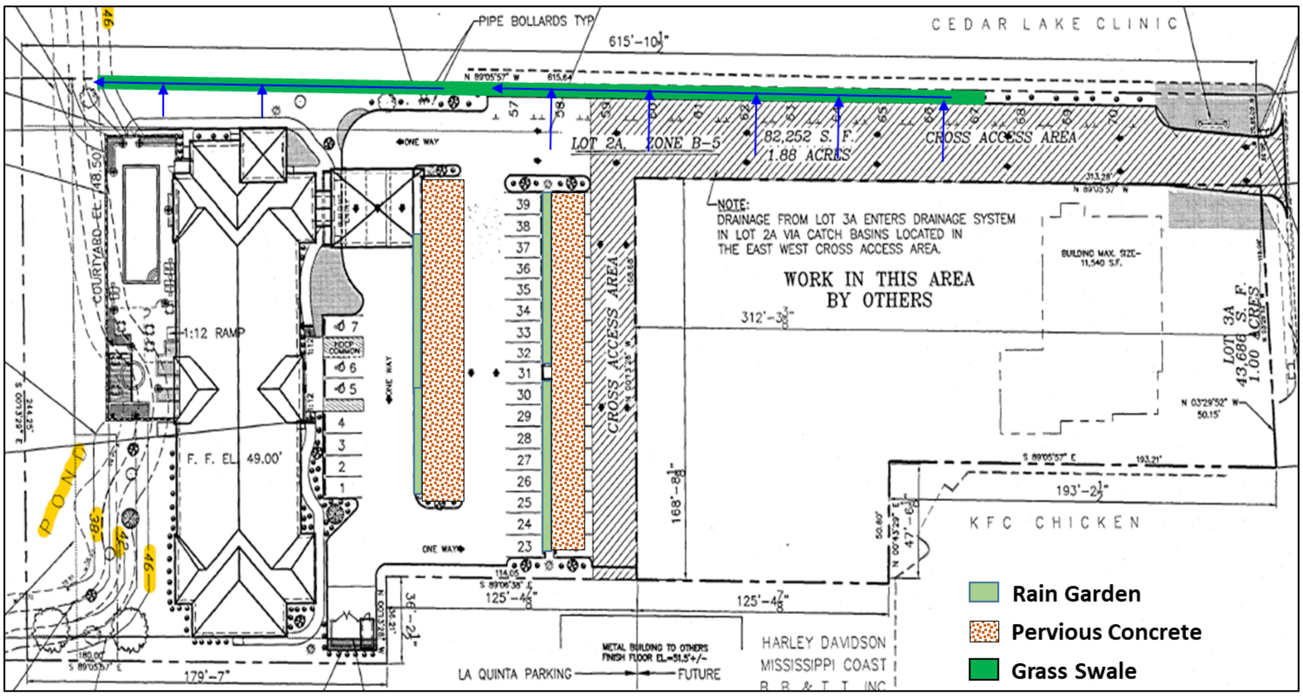


Figure 4. GSI scenarios for the La Quinta site

At the Robinson Grove site, due to three detention ponds already being part of the design and the lack of space for implementing more GSI, only a grassy ditch was proposed (Figure 5). This site poses little risk of flooding in neighboring properties because it drains directly into the Gulf of Mexico. Stormwater requirements for the site are to treat the first inch of rainfall to improve water quality. Nevertheless, we use the land use of this site as a case study that can be applied in other locations where excessive runoff can damage neighboring properties. By implementing the grassy ditch at the site, one pond (Pond 1) was eliminated and replaced by landscaping. This change creates more landscape areas than having three ponds on the site, making the site more visually appealing and usable for the occupants without increasing stormwater runoff.

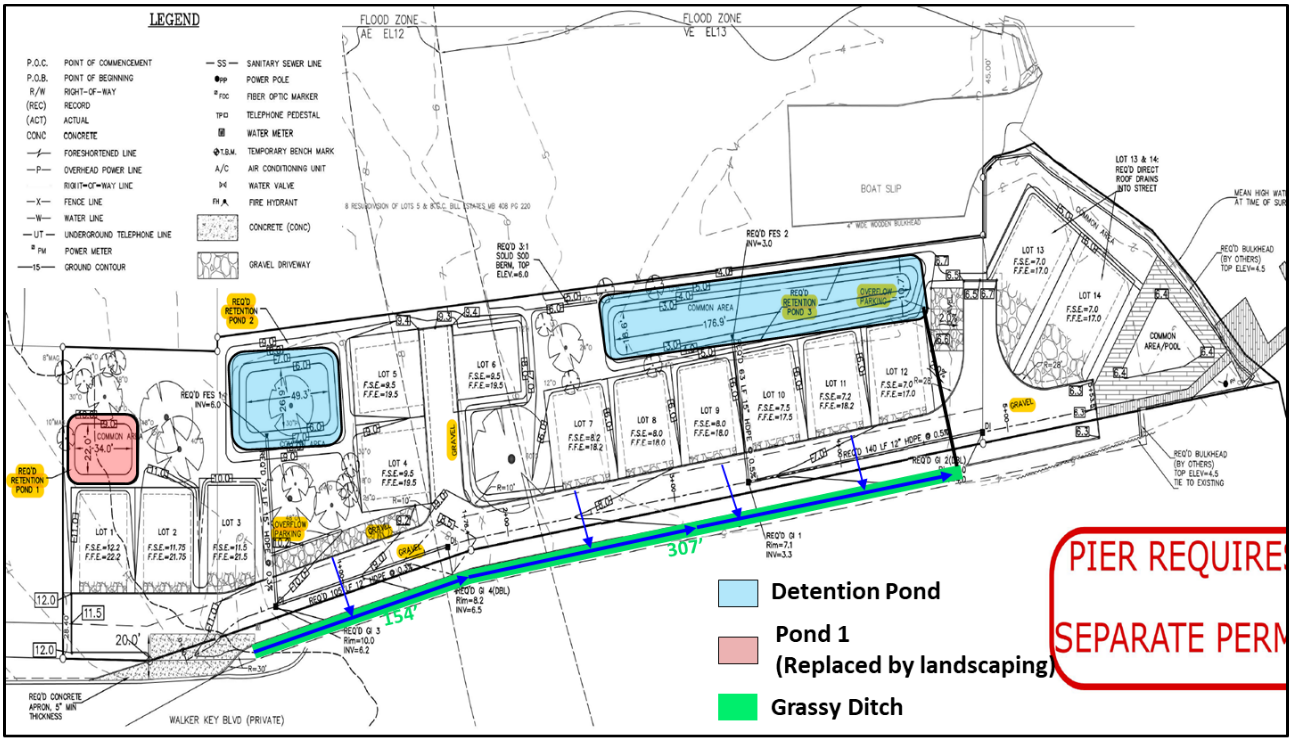


Figure 5. GSI scenario for Robinson Grove site

The scenarios shown above were all modeled in HydroCAD for the cities' design storms shown in Table 1. HydroCAD uses iterations of the NRCS Curve Number method to produce hydrographs of each scenario (HydroCAD 2019). The Baseline Scenario was simulated without GSI. The outputs of this simulation show the necessity for storage as the maximum expected peak flow leaving the site was higher than the pre-development peak in violation of city ordinances.

4.2 Modeling Green Stormwater Infrastructure

The GSI simulations were performed by adjusting the CN values and using a runoff routing method.

4.2.1 Permeable Concrete Parking Spaces

The first proposed GSI scenario was permeable parking spaces. This GSI was modeled for the La Quinta site. Some of the parking spaces were selected for the implementation of GSI based on their location. To define Scenario 1 on HydroCAD, 5,184 ft^2 of asphalt parking space was classified as permeable concrete pavement. This land cover changed the CN of the parking lot from 98 to 69. The weighted average CN of the post-development was reduced from 87 to 85. A CN of 69 was determined based on the subbase layers' potential maximum retention. The potential maximum retention of the pavement was calculated using the NRCS equation (Equation 1) and the CN of the underlying soil (Schwartz 2010; USDA 1986).

$$S = \left(\frac{1000}{CN}\right) - 10 \qquad \text{Equation 1}$$

4.2.2 Rain Gardens in the Parking Islands

Rain gardens were also modeled for the La Quinta site. Three small rain gardens with a total area of 1,215 ft^2 were included in the location of the parking islands of the site, with the remainder of the site's land cover unchanged. The rain garden was defined in HydroCAD using a pond node with the appropriate storage and outlet structures. The pond node allows defining multiple storage layers, which is appropriate to define the ponding, soil, and gravel layers of a rain garden (see Figure 7). The runoff goes through and is stored in the rain garden layers. After the layers are filled with water from the runoff, the excess runoff leaves the rain garden through an outlet structure. The water leaving the outlet structure was considered runoff generated from the system.

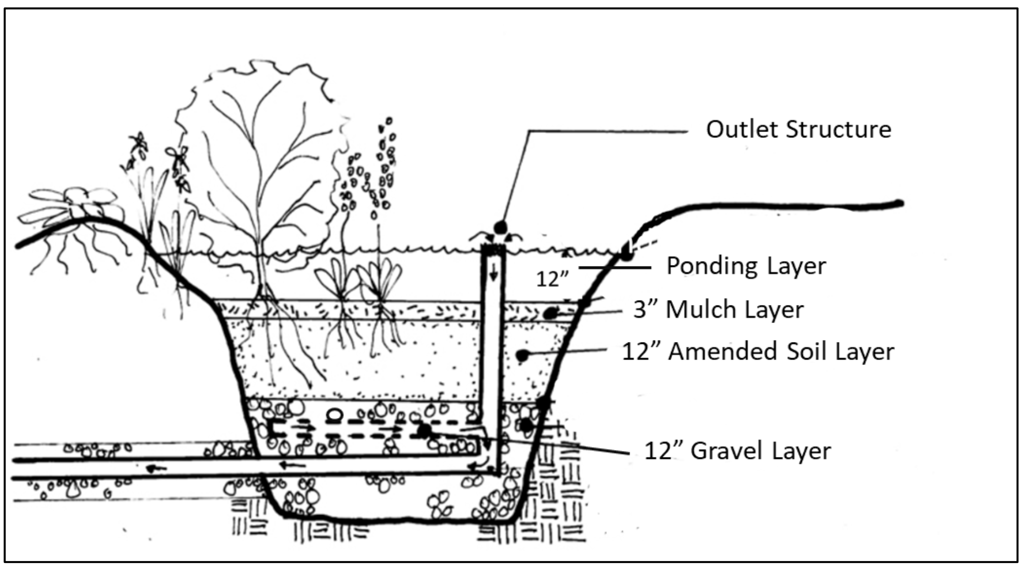
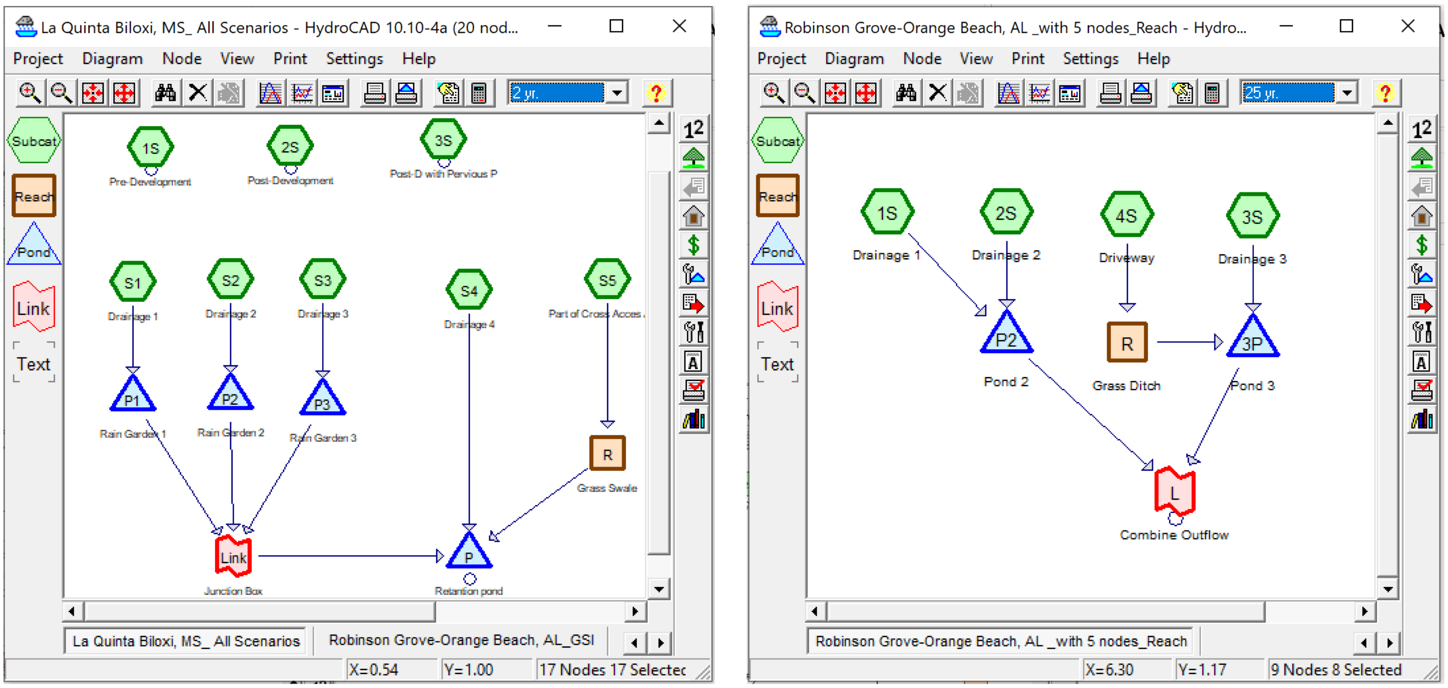


Figure 7. Rain Garden Layers

4.2.3 Grassy Ditches

A grassy ditch was modeled for both the La Quinta and Robinson Grove sites and was modeled in HydroCAD using the Reach node. The reach was defined as a trapezoidal channel that reduces the excess runoff's flow rate, allowing for increased infiltration. While the runoff travels through the channel, it infiltrates and slows the water.

Figure 8 shows the layout of GSI on the two study sites.



(a) (b)

Figure 8. GSI layouts of the study sites on HydroCAD

5 Results and Discussion

5.1 Pre- vs. Post-development modeling results

5.1.1 Site 1 – La Quinta Inn in Biloxi, MS

The pre- and post-development modeling results show that the post-development runoff peak flow and volume increased from the pre-development scenario, as expected due to the impervious surfaces. These results are summarized in Figure 9.

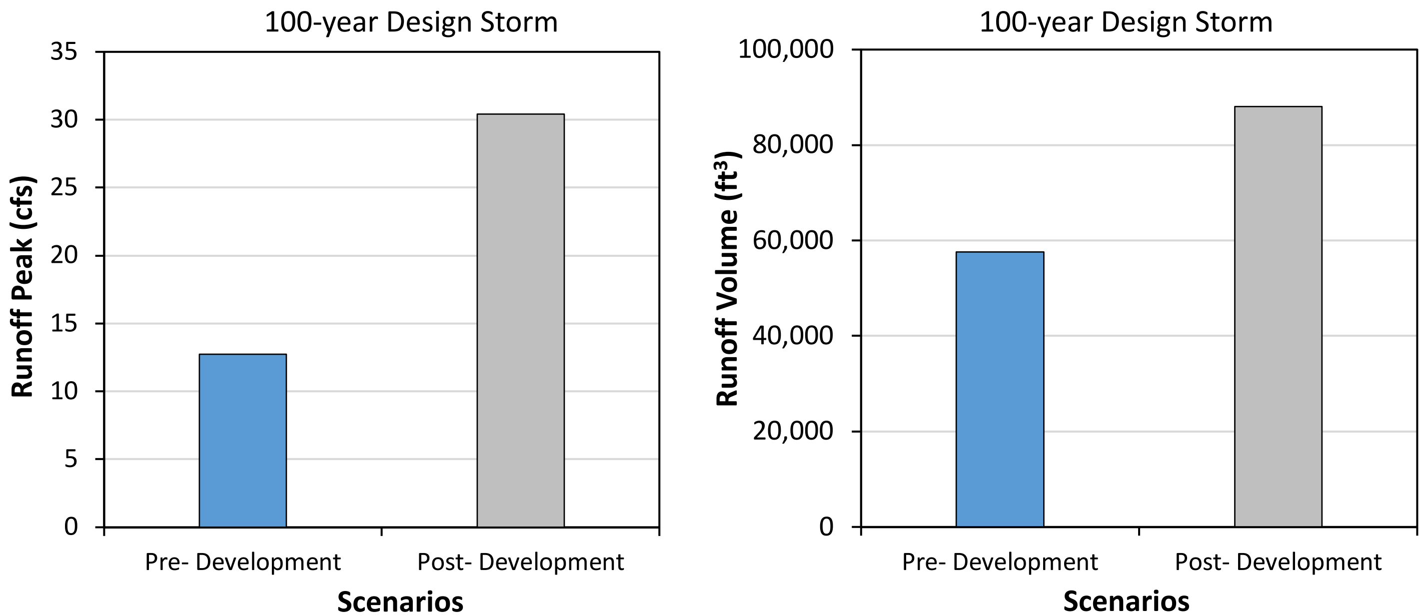


Figure 9. Pre- and post-development simulation results (a) runoff peak and (b) runoff volume.

Site 2 – Robinson Grove in Orange Beach, AL

The proposed development will double the pre-development runoff amount. Both the pre- and post-development runoff volumes and peak flows are summarized in Figure 10.

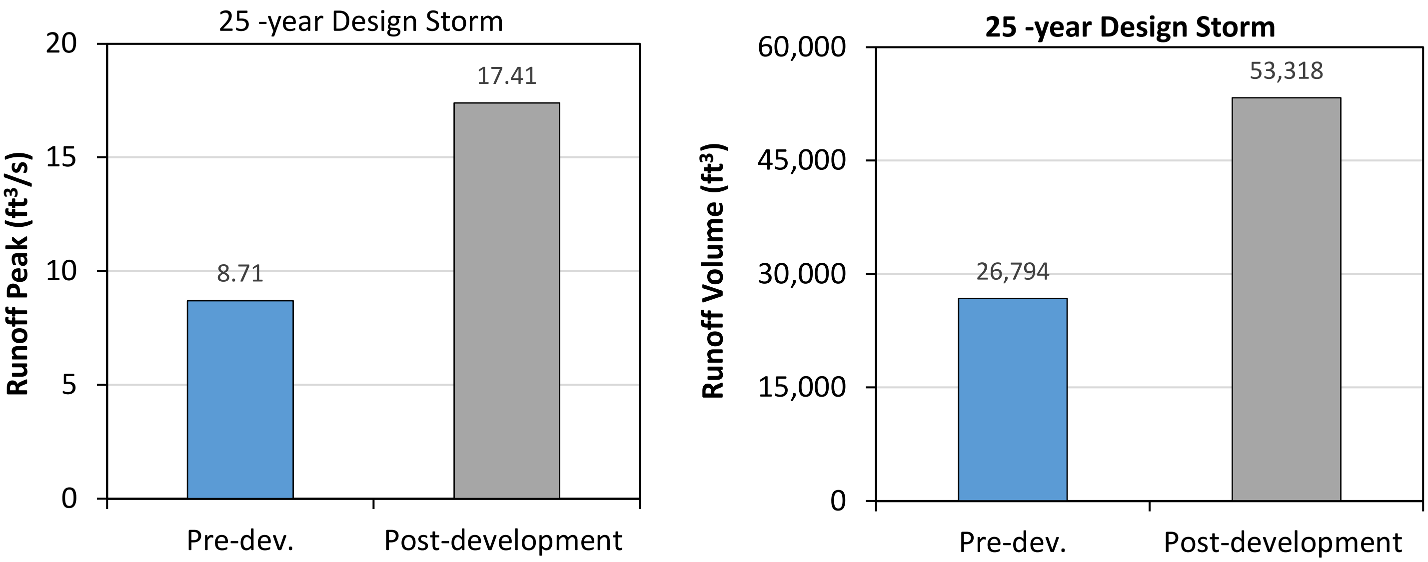
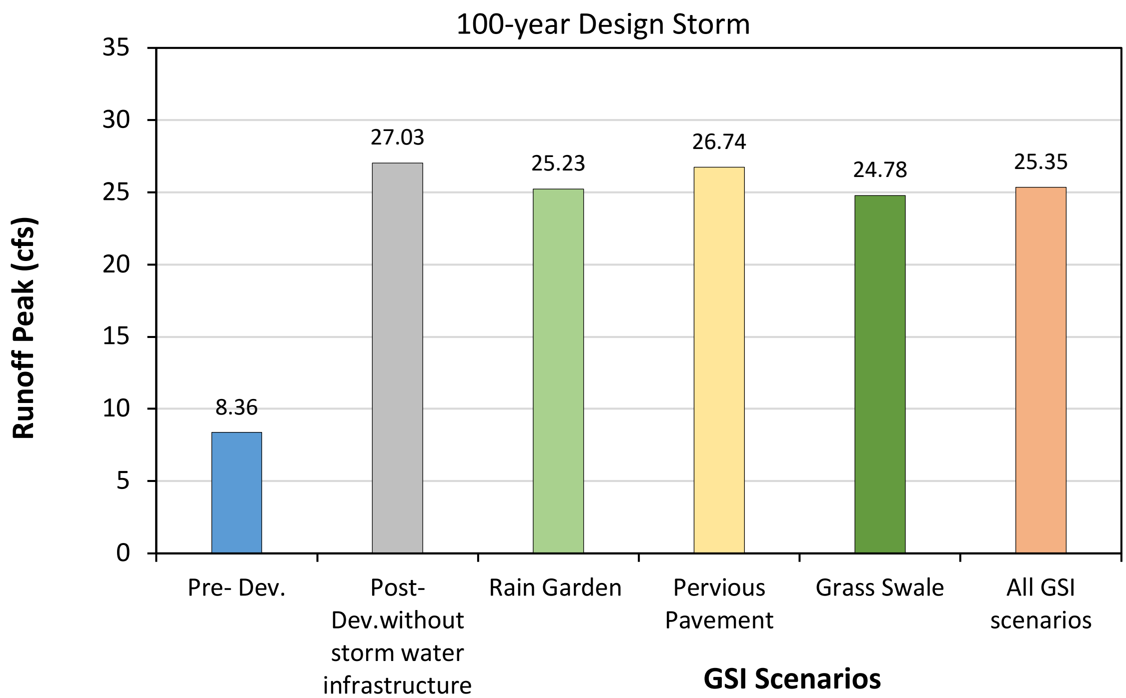


Figure 10. Pre- and post-development simulation results (a) runoff peak and (b) runoff volume

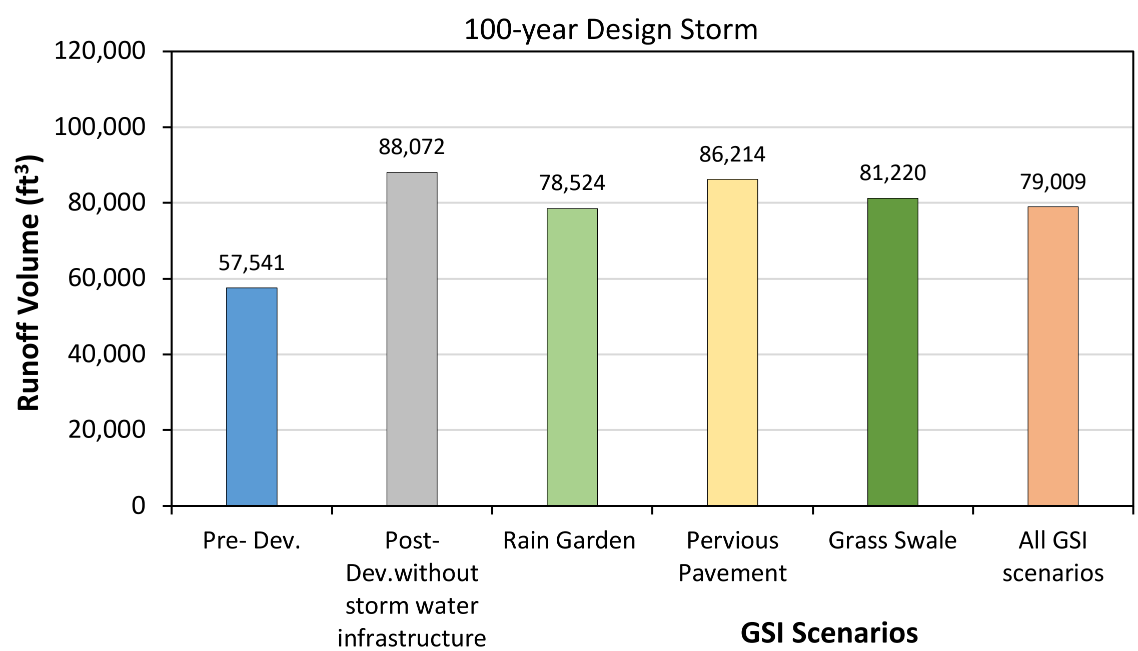
5.2 Green Stormwater Infrastructure Modeling Results

5.2.1 Site 1 – La Quinta Inn in Biloxi, MS

Based on the GSI modeling results, there was little to moderate reduction in the volume and peak runoff due to the addition of the GSI on the site. The peak flow was reduced by 7% from the post-development without stormwater infrastructure scenario, on average. However, any of the scenarios did not satisfy the pre-development peak flow requirement, see Figure 11a. Comparing the scenarios, the grassy ditch scenario (Scenario 3) showed the lowest peak flow than the other GSI. The volume of runoff reduced by 8% on average from the post-development without stormwater infrastructure scenario. The rain garden scenario showed the highest volume reduction (11%) than the other GSI scenarios (see Figure 11b.)



(a)

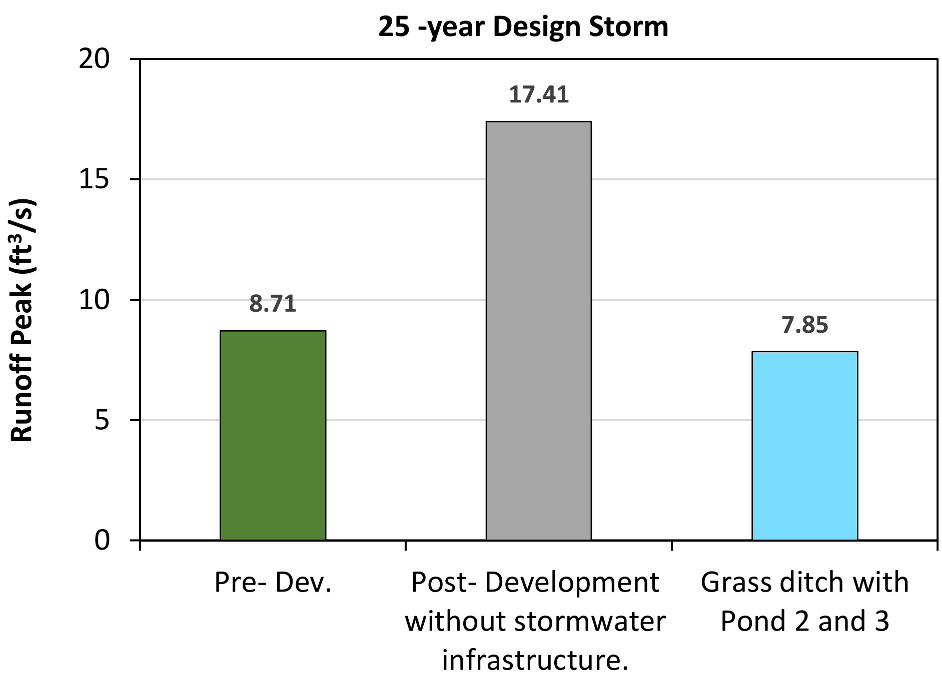


(b)

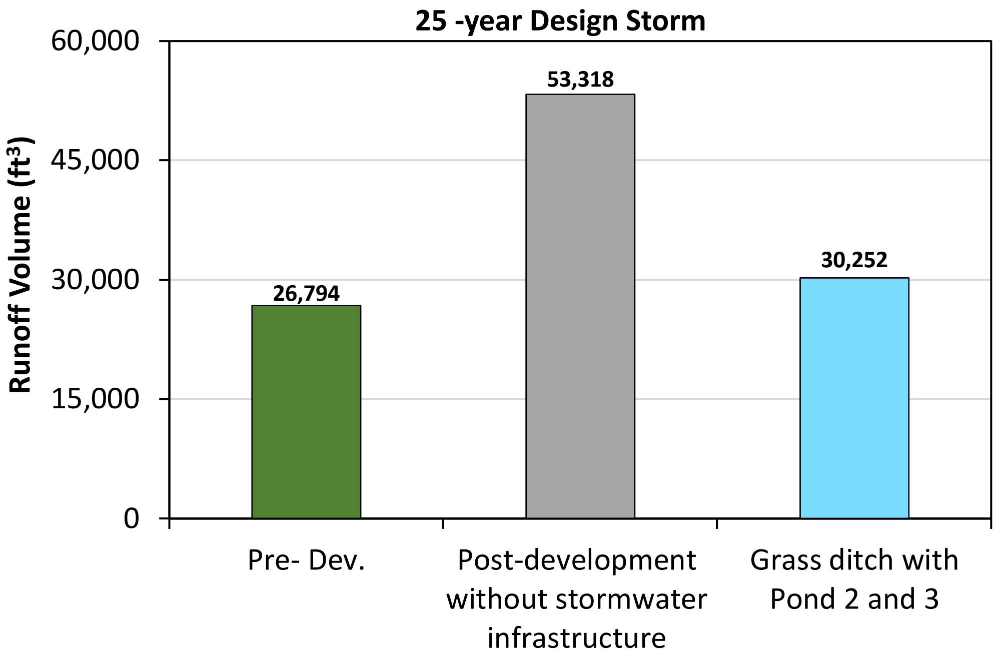
Figure 11. Runoff reduction due to GSI practices for the La Quinta site (a) peak flow and (b) volume

5.2.2 Site 2 – Robinson Grove in Orange Beach, AL

Based on the GSI modeling results, adding a grass ditch on the site and take of Pond 1 (Figure 5) showed relatively higher peak flow reduction. The peak flow from the GSI scenario satisfied the pre-development peak flow requirement. It reduced runoff by 55% from the post-development without stormwater infrastructure (Figure 12a). The runoff volume was reduced by 43% from post-development without stormwater infrastructure. However, it was 13% higher than the pre-development runoff volume, see Figure 12 b.



(a)



(b)

Figure 12. Runoff reduction due to GSI for Robinson Grove (a) peak flow and (b) volume

6 Conclusions and Recommendations

The ultimate goal of this report is for cities in the Northern Gulf of Mexico to be able to use the results of these analyses to address stormwater runoff from projects in their areas. This research assessed both residential and commercial developments, which typically have different zoning requirements regarding impermeable surfaces and landscaping. This gives other cities the opportunity to compare prospective sites in their communities to the sites analyzed in this project, and to make changes by adding green stormwater infrastructure. Particular conclusions and recommendations on the two sites analyzed are shown below.

6.1 Site 1 – La Quinta Inn in Biloxi, MS

- Based on the HydroCAD rainfall-runoff modeling results, in regards to peak reduction, a rain garden is more efficient than the other GSI. On the other hand, grassy ditches showed the highest runoff volume reduction.

- Comparing the effectiveness of the GSI practices, rain gardens achieved a higher peak flow reduction with covering relatively the smaller area. Since the requirements for stormwater management facilities design is the post-development scenario to meet the pre-development peak flow. For the La Quinta site, implementing a rain garden effectively manages the peak flow from the post-development scenario.

6.2 Site 2 – Robinson Grove in Orange Beach, AL

- For the Robinson site, adding a grass ditch and removing Pond 1 was proposed as GSI. In place of Pond 1, a landscape design was substituted. Even though the site location does not have room for adding several GSI elements, adding more landscape will increase the greenness of the site over a pond.

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