Coastal Low Impact Development Best Management Practices Inventory

2022 Summary Report






Prepared for Georgia Department of Natural Resources, Coastal Resources Division and Georgia's Coastal Management Program

Prepared by UGA Marine Extension and Georgia Sea Grant

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EXECUTIVE ABSTRACT

The *Coastal Low Impact Development Best Management Practices Inventory* ("*Coastal LID Inventory*") includes data collection for 308 green infrastructure practices in Georgia's eleven coastal counties. Practices range in size and scope yet manage 133 million gallons of stormwater runoff annually. The *Coastal LID Inventory* is an intended resource for practitioners, educators, and stormwater enthusiasts. The *Coastal LID Inventory* is foundational to greater understanding of how these systems function in coastal environments.

ACKNOWLEDGEMENTS

This project is a collaborative effort directed by the Georgia Department of Natural Resources Coastal Resources Division. Financial assistance provided by the Coastal Zone Management Act of 1972, as amended, administered by the Office for Coastal Management, National Oceanic and Atmospheric Administration and passed through the Coastal Management Program of the Department of Natural Resources.

This project would not be possible without the active partnership behind it. We would like to recognize the work of the project team members – Jessica Brown, Robert Brown, Kelly Hill, Ed DiTommaso, Lisa Gentit, Rachel Kuntz, Shannon Matzke, Colby Peffer, Dan Quinn, Jade Bailey, Annie Laura Schulz, and Alice Heminsley. Information and time invested by City and County staff was invaluable to this effort.

GEORGIA DEPARTMENT OF NATURAL RESOURCES
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TABLE OF CONTENTS

EXECUTIVE ABSTRACT....2

ACKNOWLEDGEMENTS....2

INTRODUCTION....4

Background....4

Need....4

Project Team....5

METHODOLOGY....5

Field Assessments....6

Data Analysis....6

KEY FINDINGS....8

Summaries by Practice Type....8

Summaries by County....9

Summaries by Land Use....10

Green Infrastructure Practice Performance....10

Perceived Effectiveness Rating....11

Identified Maintenance Issues....13

Practice Type Areas, Areas Treated and Annual Runoff Treated....14

Comparison of Perceived Effectiveness between 2017 and 2022 Inventory Assessments....14

GI/LID Pilot Cost Data Study....15

Study Constraints....15

GI/LID Pilot Cost Data Study Findings....16

Permeable Pavement Material Pricing....17

RECOMMENDATIONS AND FUTURE USE....19

REFERENCES....20

APPENDICES....21

I. Field Assessment Guidance Document....21

II. Data-driven GI Practice Summary Sheets....21

APPENDIX I. FIELD ASSESSMENT GUIDANCE....22

APPENDIX II. DATA DRIVEN PRACTICE SUMMARY SHEETS....27

INTRODUCTION

Background

Georgia's population is among the fastest and largest growing in the United States and the coastal Georgia region is among the fastest growing regions in the state (Hafley, 2022). Along with that growth comes infrastructure impacts. The 2019 American Society of Civil Engineers (ASCE) report card for Georgia's infrastructure cites improvement in stormwater infrastructure over the past five years, particularly as more communities are dedicating funding sources to support infrastructure upgrades, improvements, and expansions (Agramonte, Shelton, et.al., 2019). Despite the progress, substantial funding and guidance needs remain.

In 2009, the introduction of the Coastal Stormwater Supplement (CSS), a regional guidance document to the Georgia Stormwater Management Manual (GSMM), began to change the standard of stormwater management in Georgia (Novotney, Collins, et. al., 2009; Faulkner, Crowell, et. al., 2016). Prioritization of stormwater green infrastructure (GI) and the availability of low impact design criteria made these strategies available for municipalities to include in planning and design. There is still work to be done to close the gap and better understand how stormwater GI functions in a coastal environment.

Need

Low Impact Development (LID) and the utilization of stormwater GI control measures and best management practices are means of accomplishing integrated water management that aims to mimic natural hydrology. Runoff from stormwater continues to cause flooding and be a cause of water pollution in municipalities, particularly urban areas. To enhance the capacity of traditional (gray infrastructure) stormwater systems, communities have accepted installing GI systems; however, a 2017 study "*Coastal Stormwater Supplement Focus Group Recommendations*" found that a lack of training and understanding of CSS-compliant structures (i.e., GI/LID practices) is a primary barrier to implementation. The Georgia Coastal Management Program recognized this barrier and allocated NOAA (National Oceanic and Atmospheric) Office for Coastal Management funding to address the issue by funding the first inventory, the *2017 Coastal Low Impact Development Best Management Practices Inventory* ("*2017 Coastal LID Inventory*").

The *2017 Coastal LID Inventory* included data collection for 277 practices and found 220 GI/LID stormwater best management practices within 11 coastal counties. Practices manage 89.3 million gallons of stormwater runoff annually. The *2017 Coastal LID Inventory* also found that based on visual assessment three out of every four sites were experiencing <25% surface area clogging and had "good or excellent perceived effectiveness." The *2017 Inventory* study published an online map, including photos and other recorded data reflecting the status of the GI practices at the time of assessment (*2017 Coastal LID Inventory*). One of its primary recommendations was to "establish a periodic update to ensure current and relevant data are being used and allow for comparisons of individual GI practices over time." The Coastal Management Program supported two awards to complete a *2022 Coastal Low Impact Development Inventory* ("*Coastal LID Inventory"*), comparison analysis, and pilot cost study to improve the understanding of GI practices in the coastal environment, a comparison of their performance based on visual assessment and case study to obtain relevant construction cost data for GI practice implementation.

Project Team

The twelve-member project team is made up of staff from UGA Marine Extension and Georgia Sea Grant (five team members); Goodwyn, Mills, Cawood, LLC (three team members) and the Georgia Department of Natural Resources, Coastal Resources Division (four team members).

The project team brings a wide range of expertise and services in natural resources planning and design, local government funding, stormwater management, National Pollutant Discharge Elimination System (NPDES) regulatory compliance, and community-engaged research, education, and outreach. The team's collective knowledge and community engagement led to the success of this project. Four members of the 2022 project team participated in the *2017 Coastal LID Inventory* assessment and provided context for how the methodology could be improved.

METHODOLOGY

The objective of the 2022 Coastal Low Impact Development Inventory project was to update the previous version (*2017 Coastal LID Inventory*) with current information about stormwater green infrastructure practices installed in Georgia's eleven (11) coastal counties (Chatham, Glynn, Bryan, Liberty, Camden, McIntosh, Effingham, Wayne, Charlton, Brantley, Long) to create a *2022 Coastal Low Impact Development Inventory* (*"Coastal LID Inventory"*). This effort includes reassessment of the 220 sites identified in the *2017 Coastal LID Inventory*, adding, and assessing sites that have been implemented since, and documenting construction and maintenance costs for twelve green infrastructure practices ("Pilot Cost Study"). The *Coastal LID Inventory* and associated outputs will be utilized as educational resources for municipal staff and industry professionals.

The tasks identified to fulfill these objectives include database management, refining field assessment protocol, conducting field assessments, cost data collection and analysis, developing an outreach strategy and summarizing project findings.

The framework of the database and the field assessment protocol were edited to better serve the needs of the *Coastal LID Inventory*. The primary changes included: (1) the number of primary photographs was reduced to four, (2) additional photographs were organized separately and (3) contact, designer, and installer information were removed. Four photographs were prioritized to make visual data more uniform for the data summary sheets included in Appendix II. The additional contact information was removed because much of that information was unavailable. If the designer, installer, or construction date were available, that information was included in the Narrative Summary.

There are many accepted stormwater GI practices. The practice types included in the *Coastal LID Inventory* were based on those identified in the *2017 Coastal LID Inventory*, as well as outlined in the CSS. The GI practices included in the *Coastal LID Inventory* include: bioswale, bioretention, rain garden, cistern, rain barrel, stormwater wetland, green roof, and permeable pavement. The *Coastal LID Inventory* also includes an "Other" category to capture GI practices identified by local municipalities that were field assessed, but not included in this list. Many of the "other sites" were underground infiltration chambers or infiltration basins. Sites provided to the team for assessment that were not GI practices were labeled as such during field verification and removed from the public database. It should also be noted that the focus of practices selected includes those found in civic, public, commercial, and mixed land use types and while rain barrels and rain gardens are included, these practices were only assessed at publicly owned properties. Practices at individual private residences were not included because of their scale and the objective for this project was focused on locations that could be used for educational purposes, recognizing access to private property would be limited.

Field Assessments

The timeline for field assessments took place over 22 months (began in April 2021, ended in February 2023) with the majority of the assessments conducted in 2022. Reassessments were initially prioritized while new site requests were made to all coastal municipalities. Most of the practice sites were initially identified by municipalities and then field assessed. Some practices were identified while the project team was in the field and through review of aerial imagery.

All data collected for the *Coastal LID Inventory* were collected and stored in a "real-time" geographic information system (GIS) utilizing ESRI's ArcGIS Online and its corresponding Collector and Field Maps application. Goodwyn, Mills, Cawood, LLC. created the *Coastal LID Inventory* data layers. The geographic data and associated content were managed by Georgia Department of Natural Resources, Coastal Resources Division. The Georgia Department of Natural Resources, Coastal Resources Division hosts the data. The utilization of an online platform for this project has streamlined field data collection and will allow the *Coastal LID Inventory* to be managed for future updates and public use.

The majority of the *Coastal LID Inventory* work efforts were in the data collection, field assessment, and field verification of the identified practice sites. A total of 308 sites are included - 228 reassessed sites from the *2017 Coastal LID Inventory*, 80 new sites. Of the 308 sites, 276 sites had a more detailed analysis of GI practice performance. During the assessments 32 sites were unable to be evaluated, mainly due to accessibility issues. Over 70 additional sites were found to not be GI and therefore, not included in the *Coastal LID Inventory* Summary Report.

To be consistent and standardize data collection the project team initially created the "Field Assessment Guidance Document," outlining the assessment protocol. Three field assessment trainings were held during the project for project team members. A minimum of two team members visited and evaluated each site. This Guidance document can be found in Appendix I. Each site assessed has been given a unique ID code.

Data Analysis

All data collected can be found in the *Coastal LID Inventory* GIS database. A collection of photographs was taken at each location to be used for educational purposes. The project team kept field notebooks containing additional information and notes for each verified site. The field notebooks and backup for the photo database are held at Marine Extension and Georgia Sea Grant's Brunswick, Georgia location. An ArcGIS Online web application and exported attribute table (Excel file) were used to analyze and process statistics and information in this report's Key Findings section.

The area of each practice was calculated in the field, field-verified from municipality's records, or determined in the GIS using aerial imagery. The area managed by the practices were estimated to calculate annual runoff volume treated by these practices collectively. Typical sizing equations from the GSMM and CSS were used to calculate areas treated. The assumed impervious area to practice area ratio was 14:1 for bioretention and bioswales and 1:1 ratio for permeable pavement. If the field notes indicated permeable pavement only received direct rainfall, only the permeable pavement area was calculated as the area treated, and if the field notes indicated inflow was mainly/mostly direct rainfall, a ratio of 0.5:1 was used. Assumptions for the bioretention sizing include 9-in. ponding depth, 2-ft. media depth, and 6-in. gravel storage. The corresponding 25% porosity for the media and 40% porosity for the gravel were also used.

Annual runoff treated assumed that GI practices were sized for the water quality event depth and that they treat 90% annual runoff for bioretention, rain gardens, and permeable pavement, 54% for green roof, and 45% for bioswales. A runoff coefficient of 0.95 was applied to the 47.96 inches of annual rainfall (consistent with annual precipitation used in the *2017 Coastal LID Inventory*) to estimate runoff from an entirely impervious watershed. Annual precipitation data is from the NOAA weather station located at the Savannah International Airport, Station USW00003822. For green roofs and bioswales, the runoff reduction factor in the GSMM is 0.6 and 0.5, respectively. Stormwater wetlands were not included in the calculation because the GSMM assigns a runoff reduction credit of 0% to these practices. Cisterns were also not included in the calculation because the usage for each system is unknown.

To compare sites that had been evaluated for perceived effectiveness in both the *2017 Coastal LID Inventory* and the *Coastal LID Inventory* (179 sites), documented changes in visual assessment ratings were assigned "no change," "drop," or "gain" values. Each practice could "drop" or "gain" a maximum three levels between previous (2017) and current (2022) assessments (excellent → poor; or poor → excellent). A preliminary evaluation was conducted in early 2022 (80% of field assessments were complete) and again for this summary report. This evaluation was completed for the two most common types of practices permeable pavement and bioinfiltration practices (e.g., bioretention, bioswale, rain garden, and infiltration basin).

KEY FINDINGS

There is a total of 308 stormwater green infrastructure practices in coastal Georgia (11 coastal counties) that have been identified, field-verified and included in the *Coastal LID Inventory*. All these sites had required information – location, practice type, land use, surface area or storage volumes, and access information collected. In the *Coastal LID Inventory*, 32 sites were unable to be accessed for assessment during the timing of the evaluations; therefore, perceived effectiveness and maintenance information was only collected for 276 sites (204 reassessments and 72 new assessments). Please note the sample sizes in the summaries below.

Summaries by Practice Type

Approximately 61% of the practices in the *Coastal LID Inventory* are permeable pavement (187 sites), followed by 19% bioretention (58 sites), 8% bioswale (26 sites), and remaining practices ~1-2%. When grouped, bioinfiltration practices (i.e., bioretention, bioswale, rain garden), comprise 29% of the *Coastal LID Inventory*.

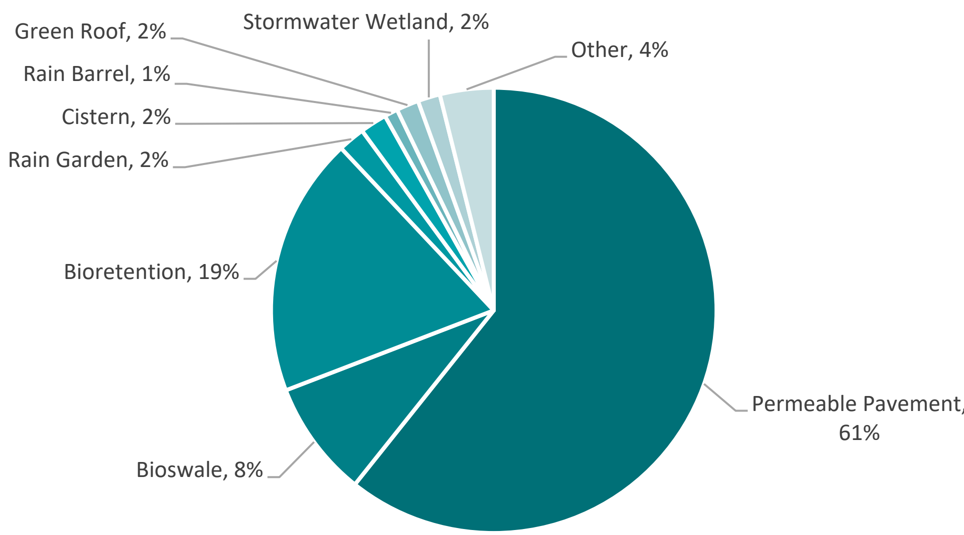

Figure 1. Practice Type (n=308)

The most common practice type in coastal Georgia remains permeable pavement (61%, 62% in *2017 Coastal LID Inventory*). When further refined, permeable interlocking concrete pavers were the most frequently used pavement type (64%), followed by pervious concrete (29%). Permeable pavement type remained consistent with distribution in the *2017 Coastal LID Inventory*.

Figure 2. Types of Permeable Pavement (n=187 sites)

Summaries by County

The urban centers of Savannah, Brunswick, and Hinesville all boost the number of practices in their respective counties. Chatham County had the most practices (205 sites) followed by Glynn County with 67 sites and Liberty County with 20 sites. All six counties adjacent to the Atlantic Ocean have at least two (2) verified practices; however, no practices were identified in the five (5) interior coastal counties (Effingham, Wayne, Charlton, Brantley, or Long). The municipal separate storm sewer system (MS4) permit regulates municipal stormwater discharges and encourages the use of stormwater green infrastructure when appropriate. All the larger MS4 permittees (Phase I Medium permittees, population >100,000) are located within Chatham County (Bloomingdale, Garden City, Pooler, Port Wentworth, Savannah, Thunderbolt, Tybee Island, and Unincorporated Chatham County). Most of the identified practices are a result of cooperative relationships with the municipalities responsible for them and their willingness to share practice information. Smaller municipalities that are not required to report GI practice information have less incentive to document or share GI location.

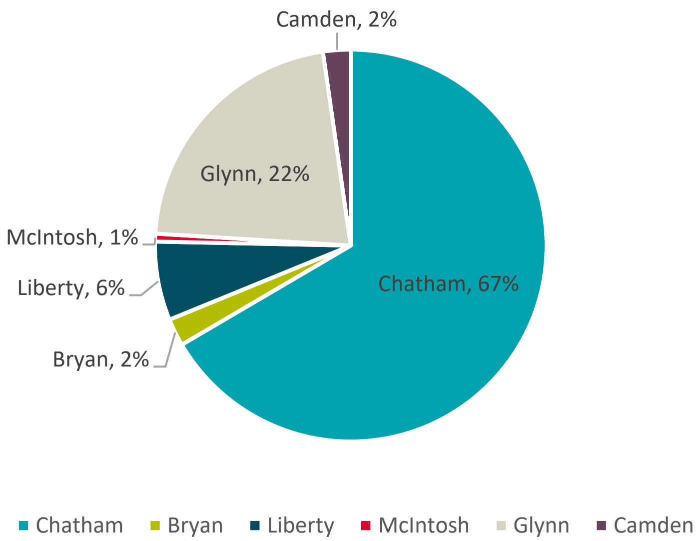

Figure 3. Percentage of practices by County (n=308)

Practice Type	Chatham	Bryan	Liberty	McIntosh	Glynn	Camden	Total
Permeable Pavement	140	4	15	1	24	3	187
Bioretention	29	2	2		22	3	58
Bioswale	16	1			9		26
Rain Garden	1		1		4		6
Cistern	2		1	1	2		6
Rain Barrel	1		1			1	3
Green Roof	5						5
Stormwater Wetland	4				1		5
Other	7				5		12
Total	205	7	20	2	67	7	

Table 1. Number of Practices by Type and County (308 Total)

Summaries by Land Use

Practices are commonly located on commercial land use sites (~53%). Of the sites assessed, 70% are located on privately-owned property.

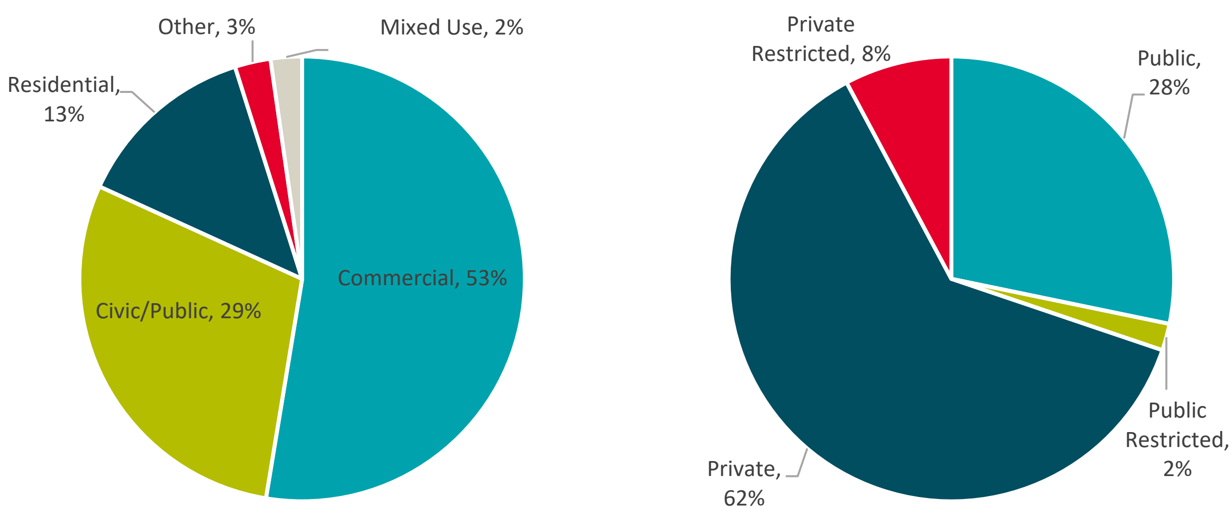

Figure 4. Summary of Land Use and Ownership (n=308)

Green Infrastructure Practice Performance

GI practices with similar functions were combined into broader categories when examining GI practice performance, shown in Figure 5. The functionality of bioretention, rain garden, bioswale, infiltration basins is similar, so these were grouped together as bioinfiltration. Similarly, cisterns and rain barrels were grouped as rainwater harvesting. Bioinfiltration and permeable pavement are the two most common groups of practices within the coastal region, representing 95% of the practices assessed.

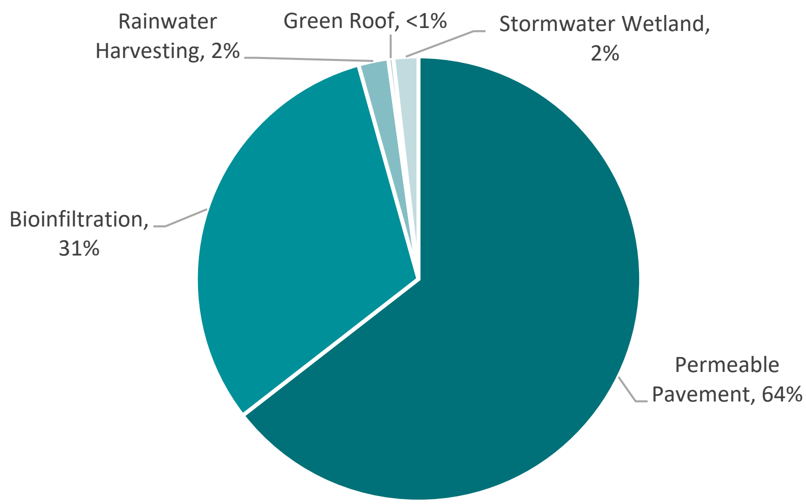

Figure 5. GI Practice Categories for Assessed Sites (n=276)

Perceived Effectiveness Rating

A total of 276 sites/practices were accessible for visual assessment to determine a rating of Perceived Effectiveness. The Perceived Effectiveness rating is an assessment of performance based on visual assessment of surface condition (level of clogging, indicators of infiltration capacity), inlet and outlet condition, presence of erosion, structural issues, vegetation (if present), and stability of the drainage area. Specific criteria were set ahead of the assessments to ensure evaluations were consistent and less subjective. Approximately one out of every eight sites (13%, 37 sites) had a rating of “poor,” indicating more than 50% of the surface area is affected by the issues above. A total of 190 sites (69%) had a “good” or “excellent” rating for perceived effectiveness, indicating <25% of the surface area is affected.

Perceived Effectiveness (n=276)						
Reassessed			New Sites in 2022		All Sites	
36	18%	Poor	1	1%	37	13%
40	20%	Fair	9	13%	49	18%
61	30%	Good	20	28%	81	29%
67	33%	Excellent	42	58%	109	39%
204			72		276	

Table 2. Summary of Perceived Effectiveness Rating (n=276)

The perceived effectiveness ratings are shown in Table 3. There were 86 bioinfiltration practices and 178 permeable pavement practices assessed (264 sites). In general, bioinfiltration practices have higher perceived effectiveness ratings compared to permeable pavement, where 88% of bioinfiltration practices were good or excellent, compared to only 58% for permeable pavement.

Practice Type	Data Series	Excellent	Good	Fair	Poor	Sites Assessed
Bioinfiltration	Reassessed	58%	27%	8%	7%	60
	New Sites 2022	81%	15%	4%	0%	26
	All Bioinfiltration	**65%**	**23%**	**7%**	**5%**	**86**
Permeable Pavement	Reassessed	17%	34%	26%	23%	133
	New Sites 2022	44%	36%	18%	2%	45
	All Permeable Pavement	**24%**	**34%**	**24%**	**18%**	**178**

Table 3. Perceived Effectiveness Ratings for Bioinfiltration Practices and Permeable Pavement (n=264)

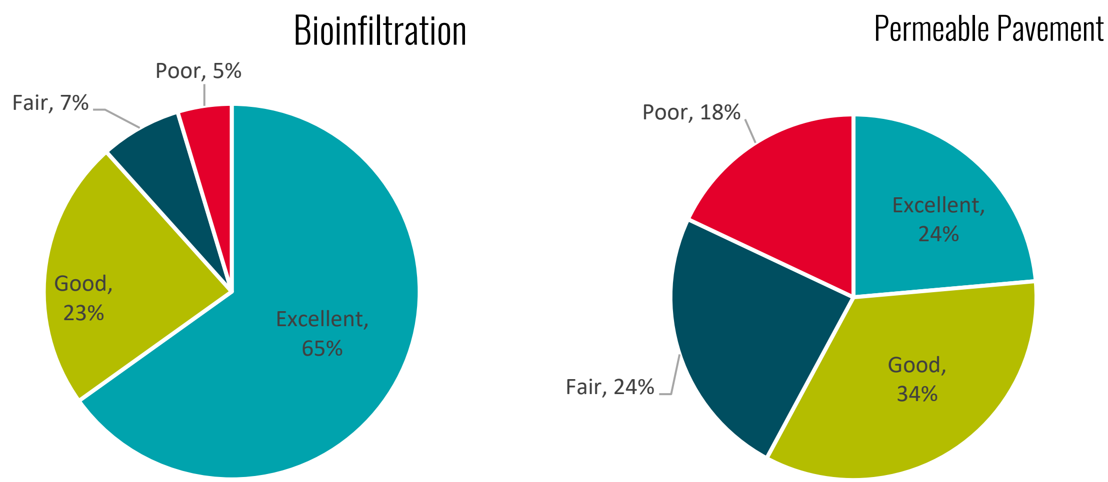

Figure 6. Perceived Effectiveness Ratings for Bioinfiltration and Permeable Pavement Practices (n=264)

For both practice types, the newer sites/newer practices are in better condition than the older, reassessed ones. This higher rating for newer sites is likely due to more recent construction, particularly if older sites have not been maintained.

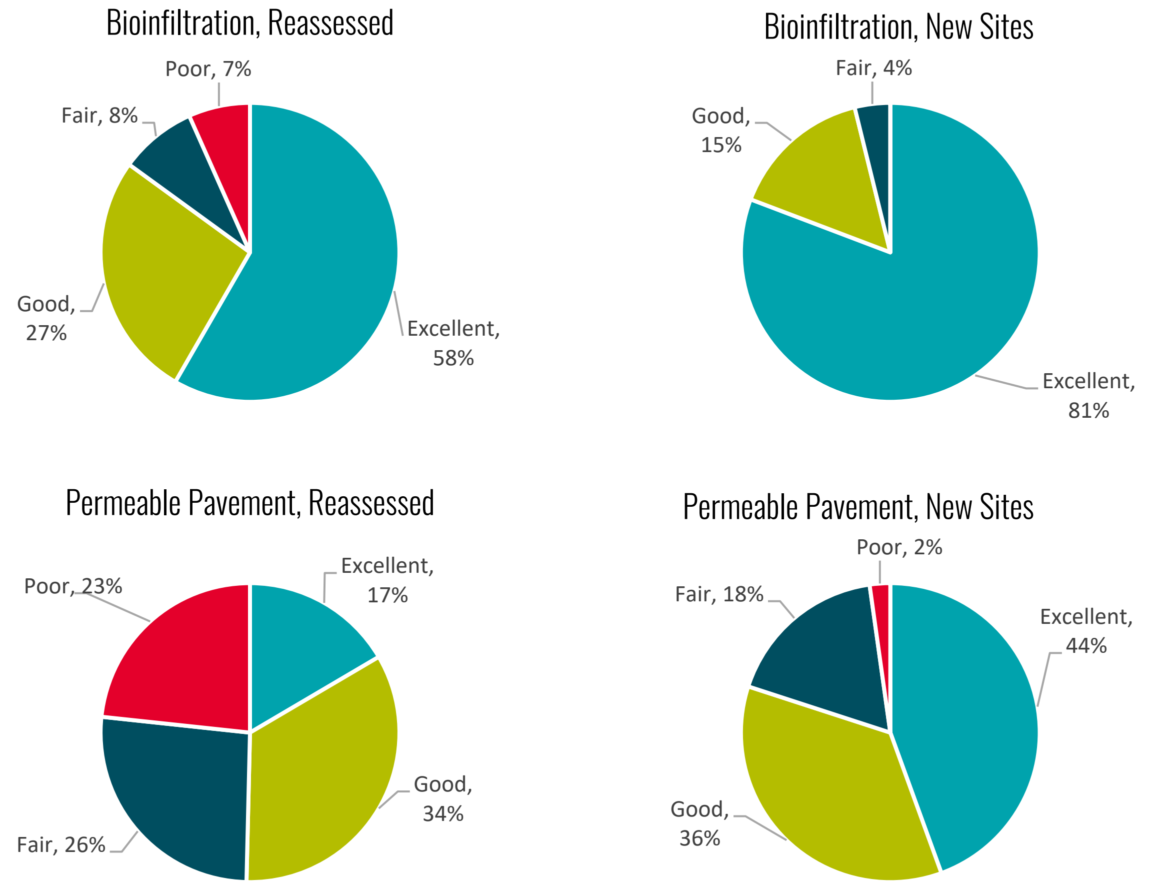

Figure 7. Perceived Effectiveness Rating Comparisons (n=264)

Identified Maintenance Issues

A more detailed look at the maintenance issues associated with bioinfiltration and permeable pavement practices shows that similarly to Perceived Effectiveness, the assessment of newer sites (added since 2017) listed fewer maintenance needs. About half of the older permeable pavement practices, which were reassessed needed maintenance due to sediment (26%) or had more than one maintenance need (23%). Of the new sites, maintenance due to sediment (9%) or more than one maintenance need (13%), was less than half. In general, bioinfiltration practices only noted a maintenance need in 28% of the sites (72% were listed as routine maintenance), where the subset of newer sites/practices was only 19% of sites with an identified maintenance need.

Practice Type Areas, Areas Treated and Annual Runoff Treated

Overall, there are 308 GI practices that manage runoff from over 127 acres and treat an estimated stormwater volume of 133 million gallons of stormwater annually.

Practice Type	Area Treated (ac)	Treatment % of Annual Runoff	Annual Volume Treated (MG/Yr.)
Bioretention	54.0	90%	64.7
Rain Garden	3.1	90%	3.7
Permeable Pavement	40.1	90%	47.0
Green Roof	0.5	54%	0.3
Bioswale	29.4	45%	17.6
Total	127.2		133.4

Table 4. Areas and Annual Runoff Volumes Treated (n=308)

The *Coastal LID Inventory* identified 22.9 acres of permeable pavement, 3.9 acres of bioretention, and 2.1 acres of bioswale – increases of 5.3, 1.4, 0.8 acres, respectively. All other practice types had minimal changes since the *2017 Coastal LID Inventory*. Over 200,000 square feet of permeable pavement was added since the *2017 Coastal LID Inventory*, resulting in an additional 9.4 acres being treated. The median site size (area) was 2,750 square feet for permeable pavement and 1,984 square feet for bioretention.

Comparison of Perceived Effectiveness between 2017 and 2022 Inventory Assessments

A primary objective of the *Coastal LID Inventory* was to compare the perceived effectiveness ratings of sites that were added in 2017 and reassessed five years later. There were 179 sites that met this criterion. 45% (80 sites) had "no change" or the perceived effectiveness rating remained static. Age or a lack of maintenance resulted in 74 sites to experience a decrease in perceived effectiveness rating, where the majority of those changes exhibited a drop of one rating (i.e., Good to Fair). Maintenance or site establishment had improved the score of 25 sites – 18 sites with one-level gained, 6 sites with two-levels gained, and 1 site that improved from poor to excellent (three-levels gained). Of the sites that maintained a perceived effectiveness rating (no change), 73% had "good" or "excellent" ratings.

Perceived Effectiveness Comparison between 2017 and 2022			
	Number of Sites		Description
-3	4	2%	Drop 3
-2	13	7%	Drop 2
-1	57	32%	Drop 1
0	80	45%	No Change
1	18	10%	Gain 1
2	6	3%	Gain 2
3	1	1%	Gain 3

Table 5. Changes in Perceived Effectiveness Rating between 2017 and 2022 (n=179)

The perceived effectiveness comparison between 2017 and 2022 was explored based on practice type. Again, bioinfiltration practices were combined. Figure 8 shows the percentages of rating changes for both permeable pavement and bioinfiltration.

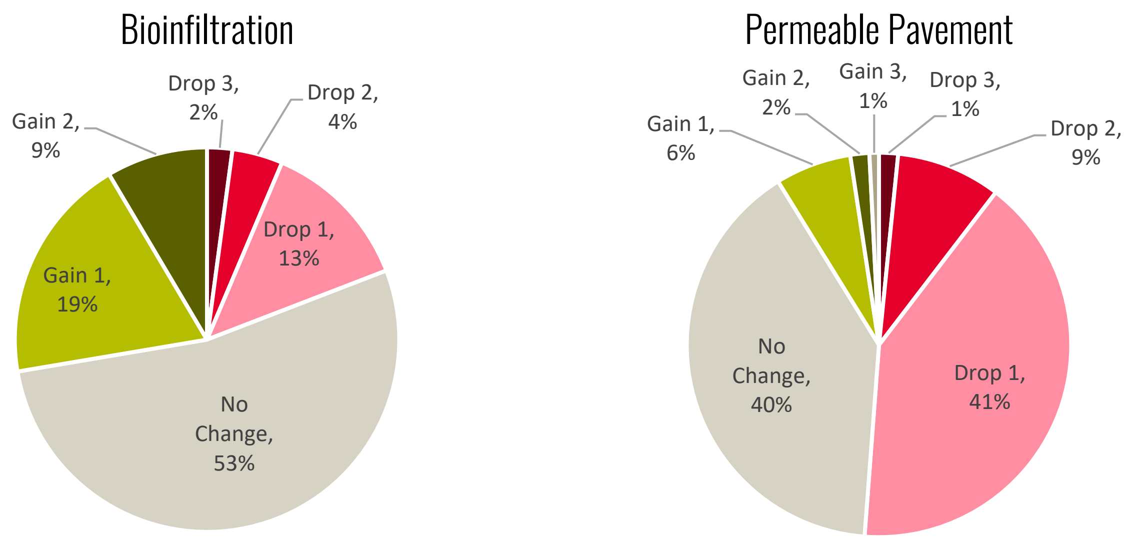

Figure 8. Changes in Perceived Effectiveness Rating between 2017 and 2022 for Permeable Pavement and Bioinfiltration practices (n=179)

Over half of the bioinfiltration practices had no change (53%) in perceived effectiveness rating with 21 of 25 sites maintaining an "excellent" rating and 13 sites gaining or increasing their perceived effectiveness (9 sites gain 1 and 4 sites gain 2). Permeable pavement sites however had 41% (51 sites) drop 1 rating which was the most common response, followed by no change at 40% (50 sites). Of the 50 sites that did not have a change in rating, there was an even distribution of ratings – 18 sites as "excellent," 11 as "good," 8 as "fair" and 13 as "poor." Only 11 permeable pavement sites (<10%) had a gain in perceived effectiveness rating.

GI/LID Pilot Cost Data Study

Twelve sites were reviewed as part of the GI/LID Pilot Cost Study. This included seven permeable pavement systems and five bioinfiltration systems that were constructed between 2018 and 2023. For the permeable pavement sites, there were four with permeable interlocking concrete pavement (PICP), two with pervious concrete, and one with plastic grid pavers. The surface area of these projects ranged from 1,312 to 15,885 square feet (SF), and the median area was 3,942 SF. For the bioinfiltration sites, there were four bioretention systems and one wet enhanced swale. The surface area of these projects ranged from 944 to 9,557 SF, and the median area was 2,400 SF.

Study Constraints

There were many variables at each site, including depth of subsurface storage layer, presence of additional drainage infrastructure, presence and size of header curbs, reporting of units, and inclusion of a demolition task, so a detailed comparison of individual line items was not feasible. In addition, midway through the time period of projects with available data (2018 to 2023), COVID-19 affected supply chain and material availability in the construction industry. Based on supply-demand and increased trucking costs, unit pricing of projects increased. Another factor impacting the analysis was GI/LID was only one component of the overall project at several sites, so several lump sum line items, such as demolition or grading were estimated for the GI/LID construction based on the GI/LID area versus disturbed area.

GI/LID Pilot Cost Data Study Findings

Overall, this study calculated total cost of the GI/LID construction and reported it based on GI/LID surface area to compare among sites. Another metric reviewed was GI/LID cost per area treated. The cost per GI/LID area was similar between the two primary practice categories – permeable pavement and bioinfiltration. The cost per area of permeable pavement ranged from \$11.28/SF to \$57.35/SF, with an average of \$27.54/SF. The cost per area of bioinfiltration ranged from \$7.38/SF to \$48.41/SF, with an average of \$30.92/SF. Both of the lowest costs for each practice type had been constructed in-house; a contractor constructed the other 10 sites. The next lowest cost per area was \$18.19/SF for permeable pavement and \$13.75/SF for bioinfiltration.

GI/LID Practice	Statistic	GI/LID Area (SF)	Cost per GI/LID Area	Cost per Area Treated	Hydraulic Loading Ratio
Permeable Pavement (n=7)	Low	1,312	$11.28	$6.07	1.0
	High	15,885	$57.35	$30.78	3.5
	Average	5,708	$27.54	$15.19	1.9
	Median	3,942	$19.88	$15.56	1.8
Bioinfiltration (n=5)	Low	944	$7.38	$0.59	9.2
	High	9,557	$48.41	$3.72	28.5
	Average	4,024	$30.92	$2.17	15.0
	Median	2,400	$42.47	$1.50	12.5

Table 6. Cost per GI/LID Area and Cost per Area Treated for Select Permeable Pavement and Bioinfiltration Practices

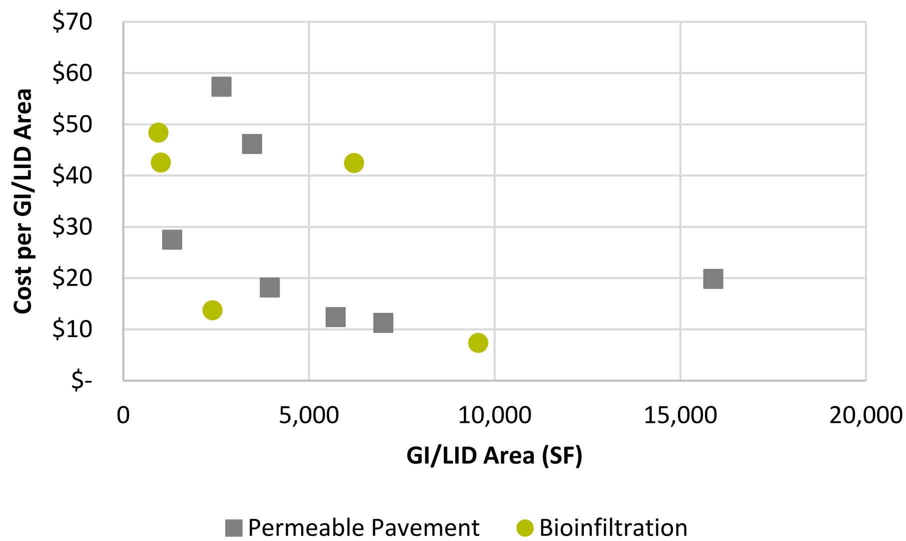

Figure 9. Cost per GI/LID Area

Once area treated was factored into the calculation, bioinfiltration is clearly a more cost-effective GI/LID practice because it has a larger hydraulic loading ratio (ratio of drainage area to practice area). Permeable pavement cost per area treated ranged from \$6.07/SF to \$30.78/SF, compared to bioinfiltration with a range of \$0.59/SF to \$3.72/SF. The average cost per area treated for permeable pavement was 7.0 times greater than bioinfiltration (\$15.19/SF vs. \$2.17/SF), and the median cost per area treated for permeable pavement was 10.4 times greater than bioinfiltration (\$15.56/SF vs. \$1.50/SF).

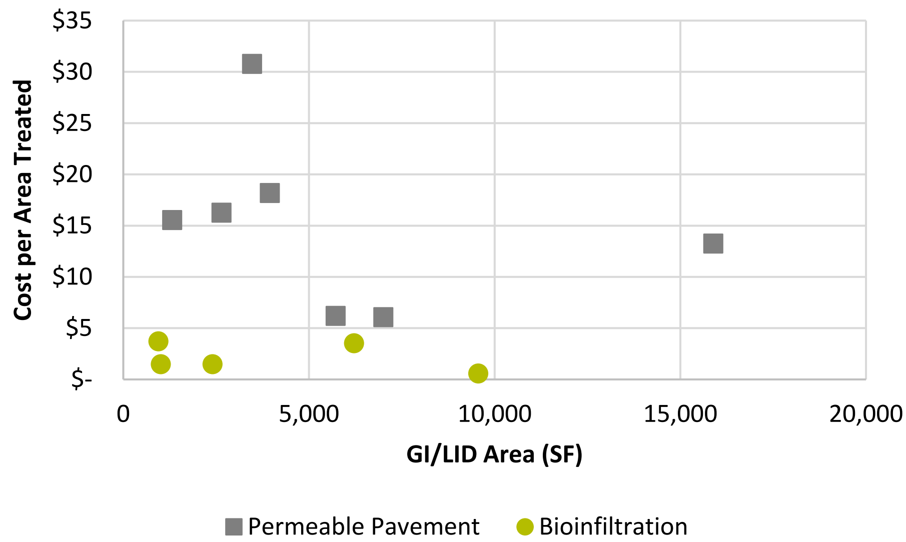

Figure 10. Cost per Area Treated

Permeable Pavement Material Pricing

Based on the available data and similarities in design, material pricing was reviewed in more detail for the permeable pavement systems. Four of the permeable pavement sites had similar average site depths, so this subset is presented in the table below to explore unit cost of the surface material and underlying stone layer. As a few notes on the two sites with lower unit costs, the site ID "JTRB201a" was constructed in-house with City of Brunswick staff and the site ID "RMK203b" is the oldest site (2018) and only one constructed prior to COVID-19. Excluding the site constructed in-house, the surface material cost is the primary cost of the pavement system when looking at surface material and underlying stone only. Surface material was between 64% and 78% of the combined costs of surface material and underlying stone, and it ranged from $8.44/SF to $11.82/SF. In comparison, the 6" subsurface stone layer ranged from $3.38/SF to $6.44/SF.

Year	Site	Pavement Type	Surface Material		Stone Layer		Avg. Site Depth	Combined Cost
			Cost/SF	*Notes*	*Cost/SF*	*Notes*	*in*	*Cost/SF*
2022 *In-house*	Brunswick (JTRB201a)[1]	Grid Pavers	$2.83	1.8" grids with #89 Stone	$2.99	10" #57	12	$8.17
2022	Skidaway Island (LCG211)	Pervious Concrete	$11.30	6" PC	$6.44	6" #57	12	$17.74
2018	Jekyll Island (RMK203b)	Pervious Concrete	$8.44	6" PC	$3.83	6" #57	12	$12.27
2023	Brunswick (under construction)	PICP	$11.82	3.1" Pavers	$3.38	6" total (2" #89; 4" #57)	9	$15.20

[1] The Stone Layer includes 8" of #57 stone plus stone in four lateral trenches that is equivalent to an additional 2" across the surface area; Combined Cost column includes City crew labor cost.

Table 7. Permeable Pavement Materials Pricing

A 6” subsurface stone layer can provide storage of 2.4” of water based on the design assumption of a 40% porosity. This can store runoff from the 1.2” water quality event that includes direct rainfall plus an impervious area equal to the permeable pavement area. This type of configuration would have a hydraulic loading ratio of 2:1; however, this does not account for any intra-event infiltration (e.g., infiltration occurring during a rain event), so the storage layer would be able to infiltrate a storm larger than the water quality event. Since the GSMM allows for an impervious area to permeable pavement area ratio of 3:1, going deeper with stone will reduce the footprint and be a more cost-effective design since the stone cost per depth is smaller in comparison to surface material. However, it should be noted that as hydraulic loading ratio increases, the subsequent sediment load will increase, and this will require more frequent inspection and maintenance. Therefore, if sites are designed with larger hydraulic loading ratios, they should be situated to minimize sediment load from the drainage area and have a comprehensive maintenance plan to ensure continued functionality.

An additional site not included in Table 7 was the site ID “RMK200a/RMK201a” project because it did not separate cost of surface material and stone, and it had a slightly deeper stone layer of 14” (2” #89 bedding and 12” #57 base layer). For that project, the combined cost was $11.42/SF. This was less than the three contractor-projects listed in the table, but it had a surface area of 19,350 SF, which was about 3.4 to 14.7 times larger than the other projects, suggesting an economy of scale. In addition, it was constructed in 2019, pre-Covid.

RECOMMENDATIONS AND FUTURE USE

Over the course of the project, the project team identified the following recommendations for future use:

- **Continue a periodic *Coastal LID Inventory* update.** A periodic update, every 3-5 years, would ensure current and relevant data are being used. Since 80 sites were added within a five-year period the GIS could be updated more frequently (annually) and analysis performed every five years. Due to recent permit changes NPDES MS4 regulated municipalities will be updating a list of GI sites annually. State agency departments should work together to request publicly available data included in NPDES MS4 Annual Reports.

- **Maintenance Resources.** Reassessment data from this project shows that older permeable pavement practices are showing a decline with age. Maintenance is critical for long-term functionality of GI practices. While much of the maintenance needs are routine, guidance for maintenance continues to be paramount. A list of qualified companies to maintain private property installations, particularly for permeable pavement is needed. The recent *Infiltration Study Summary Document* and maintenance issues identified as part of this *Coastal LID Inventory* effort suggests that older practices have more maintenance issues. Consideration should be given to a case study of permeable pavement sites with a "poor" perceived effectiveness rating, their primary maintenance issue, and potential effort to restore these practices.

- **Expand the *Infiltration Study*.** More infiltration rate data is needed to better understand how permeable pavements are functioning and the level of maintenance required for these systems in coastal Georgia. Additional monitoring and training resources are needed for municipal staff to assess infiltration rates more frequently, as one indicator of maintenance needs.

- **Motivations for types of Permeable Pavement.** Pervious concrete and permeable interlocking concrete pavers (PICP) are the most common permeable pavement type. Further information is necessary to identify if this is market-driven (availability), functionality-driven, aesthetics, or other motivation. Contractor training may be necessary to promote consistency.

- **Continue gathering and publishing cost information.** Cost data, particularly Cost per GI/LID Area Treated, creates a better understanding of cost-benefit of GI practices and informs language and communication for the most common GI practices in coastal Georgia. While the GI/LID Pilot Cost Study was informative, continuing to grow a database of cost information and an expanded study is needed. The GI/LID Pilot Cost Data Study was intended to include costs for construction and maintenance; however, there was an unwillingness to share maintenance cost data and at many sites those data were not available. As more cost data are gathered and shared, the culture of data sharing will likely improve.

REFERENCES

Agramonte, D., Shelton, R., Secrist, J., Atkinson, A., Blissit, A., Moss, B., Sauer, B. Brantley, C., Novack, C., Kelly, G., Ogonor, J., Christian, J., Chiu, J., Orton, J., Leaders, J., McLeod Gurd, K., Cole, K., Shostak, K., Prescott, L., Woods, L.,...Haynie, W. (2019). *2019 Report Card for Georgia's Infrastructure*. American Society of Civil Engineers. https://infrastructurereportcard.org/wp-content/uploads/2021/07/FullReport-GA_2019_web-1.pdf

Brown, J. and Brown, R. (2018). *Coastal Low Impact Development (LID) Best Management Practices Inventory Summary Report*. University of Georgia Marine Extension and Georgia Sea Grant.

Faulkner, C., Crowell, C., Hoffman, G., and Ricketts, J. (2016). *Georgia Stormwater Management Manual*. Atlanta Regional Commission. https://cdn.atlantaregional.org/wp-content/uploads/gsmm-2016-final.pdf

Hafley, T. (2022, February 24). *Population Change in Coastal Georgia* [Presentation, Coastal Georgia Regional Water Planning Council Meeting]. https://waterplanning.georgia.gov/document/document/projections-and-demographics-coastal-georgia/download

Novotney, M., Collins, K., Hoffman, G., and Carter, T. (2009). *Coastal Stormwater Supplement to the Georgia Stormwater Management Manual*. Center for Watershed Protection. https://epd.georgia.gov/document/document/whole-document/download