Determining Implementation Barriers for Green Infrastructure for Coastal Flood Control

Life-cycle Costs and Co-benefit Analyses 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 [Figure 1 (EPA 2018)]. GSI is often an engineered system that is designed and built based on quantitative metrics, such as urban characteristics and rainfall conditions. GSI reduces the volume and improves the quality of runoff, thereby preventing downstream flooding and environmental damage. Thus, municipal stormwater ordinances that call for GSI address two important goals with respect to federal law and policy: improve a community's score under the Federal Emergency Management Agency (FEMA) Community Rating System (CRS) program to reduce impacts from flooding, and satisfy requirements under the federal Clean Water Act to reduce pollution.

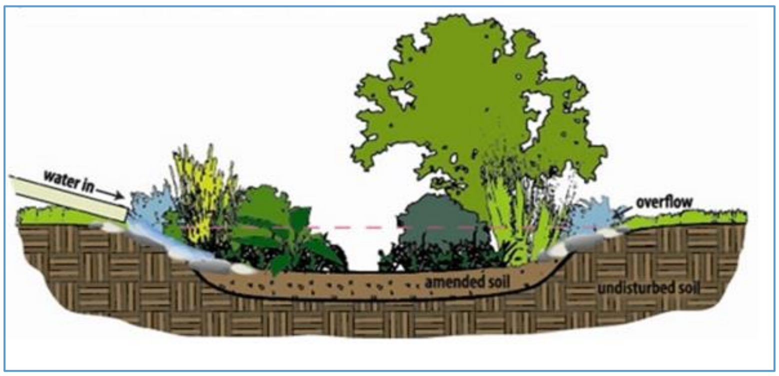


Figure 1. A bioretention cell as an example of green infrastructure, in which stormwater runoff enters and infiltrates the ground through the amended soil rather than into a storm drain. (Source: EPA, 2018)

Despite the environmental and health benefits of GSI, there are often considerable barriers to implementing these resilience practices. In 2011, the Clean Water America Alliance identified four categories of barriers that often prevent 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 addressed in this report helps overcome such barriers.

1.2 Research Project

The Mississippi-Alabama Sea Grant Consortium issued a grant to University of Mississippi researchers to analyze technical, financial, and legal barriers to implementing GSI. (U.S. Department of Commerce National Oceanic and Atmospheric Administration (NOAA) Award NA18OAR4170080.) This research aimed 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. 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. Specific barriers to the implementation of GSI identified for this project are as follows: 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). Whereas GSI can also improve water quality, such an assessment is beyond the scope of this project.

The performance of GSI in runoff reductions, life-cycle cost analysis (LCCA), and cost-benefit analysis were conducted for various GSI practices using a study site from both cities: the La Quinta Inn in Biloxi and the Robinson Grove housing development in Orange Beach. The LCCA analysis was performed for several GSI options combined with traditional stormwater control practices. The results for the LCCA are presented in this report.

2 Objectives

The ultimate goal of this report is for cities in the Northern Gulf of Mexico to use the results of these analyses to assess the financial sustainability of using GSI projects in their areas, to select the types of GSI that have the lowest life-cycle costs, and to identify financially and environmentally advantageous GSI practices.

This specific report addresses objectives 2 and 3 of the overall project objectives listed below. The results of the hydrologic performance analysis that addressed objective 1 were reported previously. The ordinance analysis, objective 4, will be presented separately.

Objective 1: Estimate changes in potential floodwater volumes based on different stormwater control structures in accordance with 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.

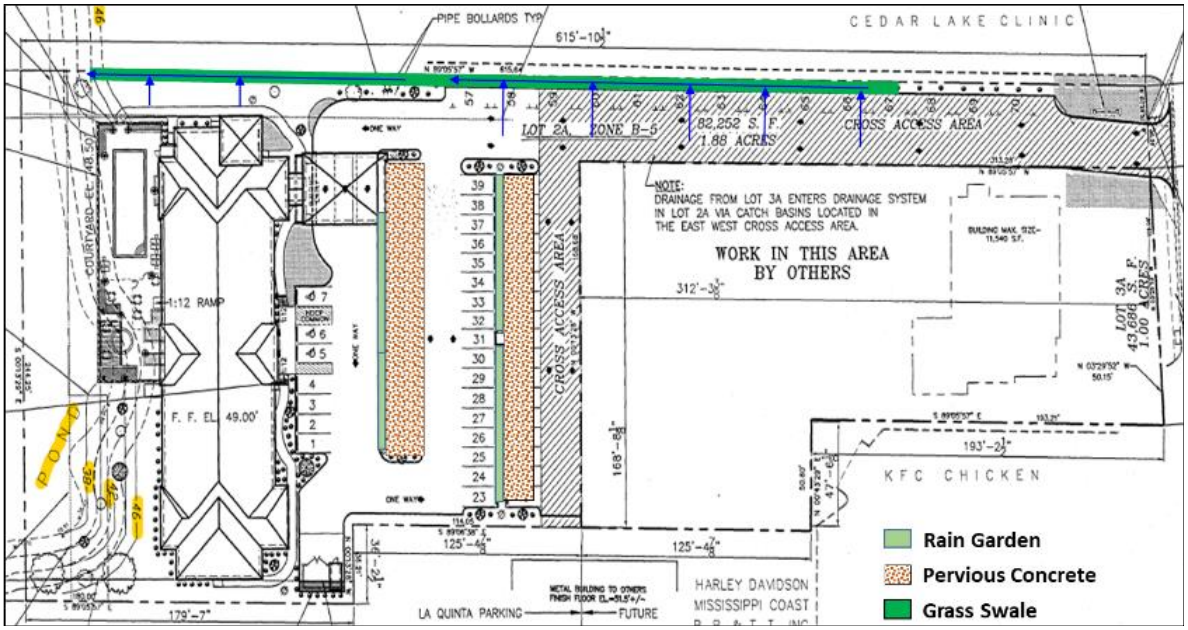
Objective 4: Modify ordinances to include flexible GSI options for coastal communities to improve their resilience to flooding.

3 Study Areas and GSI Scenarios

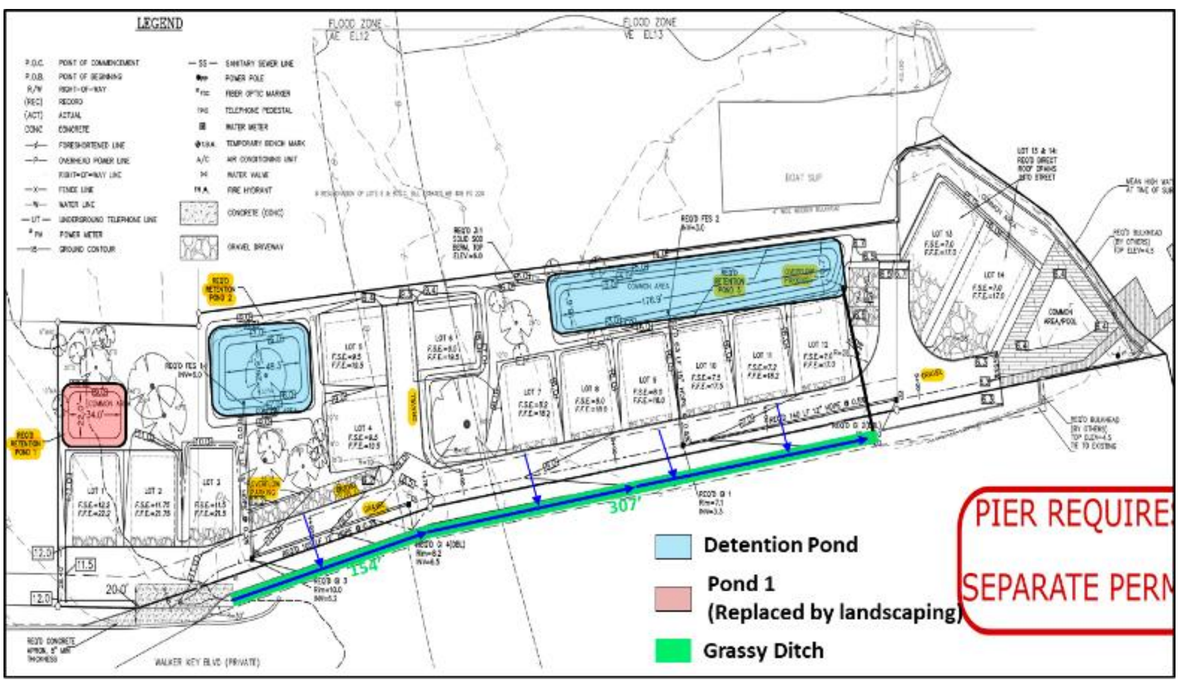
The sites analyzed for this project were the La Quinta Inn in Biloxi, MS and Robinson Grove in Orange Beach, AL. The analyses of these sites can be used as examples for other locations in the Northern Gulf of Mexico states. The costs might be different, but the differences in overall analysis methodology would be minimal.

The La Quinta site (Figure 2a) includes a three-story building, associated parking lots, a swimming pool, and a driveway. 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. Three GSIs – permeable pavements, rain gardens, and a grassy ditch – were proposed for analysis at the site (Figure 2a).

The Robinson Grove housing development site is a proposed development (under construction at the time of this writing) in a coastal city of Alabama. The development includes 14 freestanding townhouses with parking spaces underneath them, a driveway, landscaping, and a swimming pool. The total area of this development is 73,487 ft^2. Because three detention ponds are already part of the design and there is insufficient space for implementing more GSI, only a grassy ditch was proposed for analysis at the site (Figure 2b).



(a)



(b)

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

4 Methods

4.1 LCCA for various GSI scenarios

To meet Objective 2 of the overall project, the Water Environment Research Foundation (WERF) Low Impact Development (LID) cost analysis tools were used to conduct the LCCA. The cost analysis compared initial (capital) and long-term O&M costs and identified the least-cost alternative for a 30-year life-cycle period. Because the capital and O&M costs are incurred at different times in the lifetime period, the present value (PV) approach was used to combine the initial and O&M costs as a value in current dollars. The net present value (NPV) was computed using a discount rate of 5.5%. The initial and annualized costs were converted to an NPC as follows:

$$\mathrm{NPV} = \mathrm{C_0} + \sum_{t=1}^{n} \mathrm{C_y} \frac{1}{\mathrm{i(1+i)^t}}$$

where:

$\frac{1}{i(1+i)^n}$ = discount factor

C_o = initial cost (capital cost)

C_y = O&M cost in year y

i = discount rate, 0.055

n = life-cycle period, 30 y

t = years 1 to n

The LCCA was conducted for traditional stormwater detention and traditional stormwater detention and GSI settings. The WERF LID cost analysis tools considered three maintenance activities for pervious concrete pavement: inspection, litter removal, and sweeping. For rain gardens and grassy ditches, regular maintenance and corrective and infrequent maintenances were considered in the cost estimation (WERF 2009). Furthermore, for comparison, the costs of exchanging asphalt pavement for pervious pavement and landscaping for rain gardens and grassy ditches were estimated.

4.2 Co-benefit analysis

To meet Objective 3 of the overall project, a co-benefit analysis was conducted using the Community-enabled Life-cycle Analysis of Stormwater Infrastructure Costs (CLASIC) tool. CLASIC is an online tool that fully interfaces with geographic information systems and links with national databases to upload data for the modeled area at a community level. Unlike WERF LID, CLASIC uses a life cycle cost framework to support the feasibility and planning of stormwater infrastructure (WRF 2021). The tool integrates three components: life cycle cost, performance, and co-benefits. The co-benefit component enables consideration of co-benefits for green infrastructure.

The values of co-benefits were assessed for the so-called triple bottom line (TBL) benefits: social, economic, and environmental. The co-benefit analysis considered direct benefits/consequences of the GSI scenarios. The purpose was to compare the results with the scenarios' life-cycle cost and hydrologic performance (WRF 2021). For both sites, the analysis was performed with the proposed GSIs. The scenarios without GSI were set as a baseline.

The CLASIC tool includes 10 GSI practices, including a rain garden and permeable pavement. However, a grassy ditch is not available in the tool. We are testing the benefits of a grassy ditch after a city engineer from one of the partner cities raised the grassy ditch idea. It is a long open grass-lined channel. The purpose of the grassy ditch is to slow down runoff by holding the runoff in a ponding layer and releasing it slowly. It differs from a swale as it is not connected to another waterbody and is not intended as a conduit for water but as a retention device to promote infiltration. Because the channel is open and shallow, the design facilitates the performance of maintenance activities.

Because a grassy ditch is not one of the GSIs used by CLASIC, the infiltration trench option was used to define it in the tool. However, an infiltration trench has a different design than a simple grassy ditch; therefore, modifications were made on the input parameters to define the ditch, especially when defining the storage depth. The trench depth was adjusted to define the storage size of the ditch. Furthermore, because an infiltration trench costs more than a grassy ditch, the cost data were adjusted to match the estimated cost of the ditch during the LCCA.

CLASIC provides a list of indicators under the three co-benefit categories. The user can select the indicators that must be considered for the assessment. Also, the importance of each indicator was defined as follows: 1 – Not Important, 2 – Somewhat Important, 3 – Medium Importance, and 4 – Very important. Table 1 shows the importance levels of the co-benefit indicators considered in this analysis.

Table 1: Importance level of the co-benefit indicators

Co-benefi	Indicators	Importance Level
Social	Health Impacts from Air Quality	3
	Mental Health	2
	Thermal Comfort	2
	Increased Supply from Harvested Stormwater	NA
	Public Awareness of Stormwater and Water Systems	3
	Potential Avoided Social Strain Associated with Nuisance Flooding	4
Economi	Property Values	3
	Costs from Illness	2
	Avoided Cost from Combined Sewer Treatment	NA
	Potential Impacts from Nuisance Floods	4
	Building Energy Efficiency	1
	Avoided Water Treatment	NA
	Employment Opportunity	1
Environment	Ecosystem Services	3
	Groundwater Flow Increase	3
	Carbon Sequestration	3

5 Results and Discussion

5.1 LCCA Results

In this section, the estimated life-cycle cost results based on the WERF LID tool will be presented for the two study sites.

5.1.1 Site 1 – La Quinta Inn in Biloxi, MS

For Site 1, the life-cycle costs of using only traditional stormwater retention and of using both traditional detention and GSI scenarios were estimated using the WERF LID tool. Table 2 summarizes the NPVs of all the scenarios based on the LCCA calculations. Adding GSI on the site increases the life-cycle cost for all GSI scenarios (Table 2). The costs differed based on the type of GSI and the area covered by the GSI. The NPV cost for pervious concrete pavement was higher than for the other scenarios. The grassy ditch scenario resulted in a smaller NPV.

5.1.2 Site 2 – Robinson Grove in Orange Beach, AL

Based on the LCCA results, adding a grassy ditch at the Robinson Grove site increased the life-cycle NPV cost by $22,618, similar to the results at the La Quinta site. The Robinson Grove site cost changes are shown in Table 3.

In general, by comparing only the capital and O&M costs, implementing GSI might not be more cost-efficient than traditional stormwater management. However, implementing GSI has other cost co-benefits, such as reducing the potential of flooding, which is not accounted for in the direct costs used in the LCCA. Reducing flooding would save money for property owners and the city. These are the types of co-benefits in the analysis.

Table 2: Present Value of Costs of all Scenarios (La Quinta site)

Stormwater Infrastructur	Traditonal Stormwater Infrascture (baseline scenario)		Green Stormwater Infrastructure Scenarios							
			Rain garden on the parkingds		Pervious concrete on some of the parking spaces		Grassy ditch on the north side of the site		Combination of all GSI Scenarios	
	Capital	**O&M**	**Capital**	**O&M**	**Capital**	**O&M**	**Capital**	**O&M**	**Capital**	**O&M**
Asphalt Pavement	$36,288	$3,285	$36,288	$3,285	-	-	$36,288	$3,285	-	-
Landscape	$9,200	$23,441	$3,125	$16,779	$9,200	$23,441	$6,075	$20,018	-	-
Rain Garden	-	-	$9,720	$20,018	-	-	-	-	$9,720	$20,018
Pervious Pavement	-	-	-	-	$77,760	$10,892	-	-	$77,760	$10,892
Grassy ditch	-	-	-	-	-	-	$4,035	$12,679	$4,035	$12,679
Retention Pond	$0	$36,334	$0	$36,334	$0	$36,334	$0	$36,334	$0	$36,334
Tota	**$45,488**	**$63,060**	**$49,133**	**$76,418**	**$86,960**	**$70,667**	**$46,398**	**$72,317**	**$91,515**	**$79,923**
Total Cost	**$108,548**		**$125,551**		**$15**		**$118,715**		**$171,438**	
Differe (without GSI - with GSI)	**$0**		**-$17,002**		**-$49**		**-$10,166**		**-$62,890**	

Table 3: Present Value of Costs of All Scenarios (Robinson Grove site)

Stormwater Infratructure	Tradititormwater Infrastruure (baseline scenario)		Green Stormwater Infrastructure Grassy Ditch	
	Capital	**O&M**	**Capital**	**O&M**
Pond 1	$2,210	$6,424	$0	$0
Pond 2	$3,810	$11,075	$3,810	$11,075
Pond 3	$9,995	$29,053	$9,995	$29,053
Grassy Ditc	-	-	$3,536	$13,897
Landscapin	-	-	$2,188	$11,632
Total	**$16,015**	**$46,552**	**$19,529**	**$65,656**
Total Cost	**$62,567**		**$85,185**	
Difference (without GSI – with GSI)	**$0**		**- $22,618**	

5.2 Co-benefit Analysis Results

This section presents the co-benefit analysis outputs based on the use of the CLASIC tool. The tool provides the results on a scale of 0-5 for the three co-benefit categories: economic, social, and environmental. The score is calculated based on the assigned importance level of each co-benefit indicator based on a multi-criteria decision analysis (see Table 1 for the importance level of each indicator under the three co-benefit categories).

5.2.1 Site 1 – La Quinta Inn in Biloxi, MS

The co-benefit results are reported on a scale of 0-5, where 5 is most beneficial. The overall score was estimated based on the co-benefit indicators for each social, economic, and environmental category based on a multi-criteria decision analysis.

For Site 1, the rain garden scenario had the highest score for the three co-benefit categories. Comparing these categories, the highest score was shown for the environmental co-benefits with a score of 3.57. The scores were 2.59 for social co-benefits and 2.45 for economic co-benefits. The co-benefit scores for the permeable pavement, grassy ditch, and all scenarios combined are shown in Figure 3. Based on these results, the rain garden is the best scenario with the highest benefits compared to the other GSI scenarios scores (Figure 3). Furthermore, as reported in the LCCA section, the rain garden scenario was the most economical option with smaller NPV costs than the other GSI scenarios. Both the LCCA and co-benefit analysis results were consistent.

Figure 3: Co-benefits of GSI scenarios (a) rain garden on parking islands, (b) pervious concrete on parking spaces, (c) grassy ditch on the north side of the site, and (d) combination of all scenarios (La Quinta site).

The co-benefit analysis was also performed for the combination of all the scenarios (Figure 3d), not surprisingly yielding a higher score than the individual scenarios, especially for the social and environmental co-benefits. Each co-benefit was measured based on the importance of individual indicators considered. The importance level of each indicator, as shown in Table 1, was set based on the research objective. CLASIC also provided detailed score results for each indicator under the three benefits.

Table 4 shows the score for each indicator that contributes to social, economic, and environmental category performance. Note that a score of 5 does not indicate that the scenario performs at the maximum potential for an indicator, but that it performs best compared to other scenarios (WRF 2021).

Table 4: Scores of co-benefit indicators for all GSI scenarios (La Quinta site)

Co-benefit	Indicators	Score			
		Rain Garde	Pervio Pavement	Grassy Ditch	All GSI Combined
Social	Health Impacts from Air Quality	5	0	0	5
	Mental Health	5	0	0	5
	Thermal Comfort	1.6	2.3	5	2.4
	Public Awareness of Stormwater and Water Systems	1.1	1.8	2.2	5
	Potential Avoided Social Strain Associated with Nuisance Flooding	2.5	3	3	5
Economi	Property Values	5	0	0	0
	Costs from Illness	5	0	0	5
	Potential Impacts from Nuisance Floods	2.5	3	3	5
	Employment Opportunities	1.4	1.1	1.3	5
Environmeal	Ecosystem Services	3.3	0	0	3.3
	Groundwater Flow Increase	2.4	3.2	3.2	5
	Carbon Sequestration	5	0	0	1.5

5.2.2 Site 2 – Robinson Grove in Orange Beach, AL

For Site 2, only a grassy ditch was proposed for modeling because of space constraints. Of the social, economic, and environmental co-benefits, the highest score was reported for the social co-benefits: 2.06. The scores for social and economic co-benefits were the same: 1.67, as shown in Figure 4.

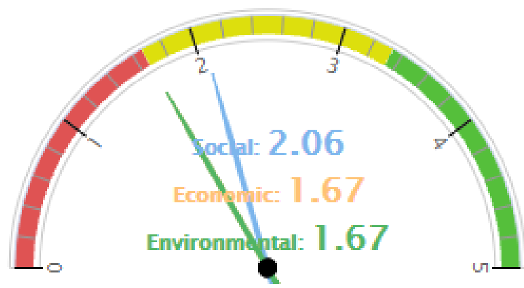


Figure 4: Co-benefits of grass ditch on the north side of the site (Robinson Grove)

Table 5 shows the score for each co-benefit indicator. Even though the grassy ditch did reduce the peak and volume of runoff from the stormwater study for Objective 1 of the overall report, the corresponding environmental and health co-benefits were comparatively less significant.

Table 5: Co-benefit indicator scores for all GSI scenarios (Robinson Grove)

Co-benefit	Indicators	Score
		Grassy Ditch
Social	Health Impacts from Air Quality	0
	Mental Health	0
	Thermal Comfort	0
	Public Awareness of Stormwater and Water Systems	5
	Potential Avoided Social Strain Asso with Nuisance Flooding	5
Economic	Property Values	0
	Costs from Illness	0
	Potential Impacts from Nuisance Floo	5
	Employment Opportunity	5
Environment	Ecosystem Services	0
	Groundwater Flow Increase	5
	Carbon Sequestration	0

6 Conclusions and Recommendations

6.1 Site 1 – La Quinta Inn in Biloxi, MS

- Based on the LCCA results, the NPV cost with GSI scenarios is higher than for traditional stormwater infrastructure.
- Comparing the proposed GSIs for Site 1, the rain garden scenario is more cost-efficient than the other GSI scenarios based on the LCCA.
- Based on the co-benefit analysis result, the rain garden scenario has the highest social, economic, and environmental co-benefits. Therefore, the rain garden scenario is the most cost-efficient option for the sites.

6.2 Site 2 – Robinson Grove in Orange Beach, AL

- Adding a grassy ditch on Site 2 increases the NPV of the LCC. However, even though the co-benefits are relatively insignificant based on the measuring scale, the grassy ditch also has some environmental and health co-benefits.

In general, incorporating GSI on development sites increases the project's cost because these practices need routine maintenance. However, GSI also provides environmental and social co-benefits to various extents, depending on the type of GSI and the value placed on those co-benefits.

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