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5105

Advancing Benefits and Co-Benefits Quantification and Monetization for Green Stormwater Infrastructure: An Interactive Guidebook for Comparison Case Studies

CLASIC

Advancing Benefits and Co-Benefits Quantification and Monetization for Green Stormwater Infrastructure: An Interactive Guidebook for Comparison Case Studies

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THE Water Research FOUNDATION

The Water Research Foundation (WRF) is the leading research organization advancing the science of all water to meet the evolving needs of its subscribers and the water sector. WRF is a 501(c)(3) nonprofit, educational organization that funds, manages, and publishes research on the technology, operation, and management of drinking water, wastewater, reuse, and stormwater systems—all in pursuit of ensuring water quality and improving water services to the public.

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Abstract and Benefits

Abstract:

As the world faces ever-increasing community challenges associated with climate change and water quality standards, the role and importance of green stormwater infrastructure (GSI) is expanding. GSI can be used to enhance recreation and quality of life, reduce the effects of excessive heat and the urban heat island effect, improve air quality and habitats, offset climate change, and restore ecosystems. In addition, GSI can be used to reduce operational costs for stormwater management, reduce nuisance flooding, reduce irrigation needs, increase property values, and create long-lasting jobs for the local economy. GSI is an equitable approach for wet weather impacts because it is a tool that can mitigate situations that tend to disproportionately impact disadvantaged areas of a community, such as urban heat stress. For these reasons, many utilities and municipalities have explored the use of GSI as a cost-effective way to build resilience into their systems while providing benefits and co-benefits to its users.

Quantifying benefits attributable to GSI systems provides utilities and municipalities with a holistic view in evaluating future stormwater investments. Conventional cost analyses for such comparisons typically include a review of initial capital costs (e.g., planning, design, and construction) and lifecycle costs (e.g., operation and maintenance, replacement costs, and end of life costs). However, this approach is limited as it does not account for the full range of benefits that can be achieved with GSI, and therefore does not provide an accurate basis for reviewing design alternatives. For this reason, gray infrastructure may appear more cost-effective than GSI.

Conversely, a triple bottom line cost-benefit analysis quantifies and monetizes the costs and benefits (or disbenefits, as appropriate) of employing design alternatives with a focus on financial, social, and environmental outcomes. This approach ensures that holistic costs and benefits of each alternative are presented to the decision makers, and ultimately allows for better and more complete decisions to be made with limited resources.

The Water Research Foundation (WRF) previously funded two projects for evaluating benefits and co-benefits of GSI:

- Community-enabled Lifecyle Analysis of Stormwater Infrastructure Costs (Project 4798), (“CLASIC”) (WRF, 2023)
- Economic Framework and Tools for Quantifying and Monetizing the Triple Bottom Line Benefits of Green Stormwater Infrastructure (Project 4852 / SIWM4T17), (“GSI TBL Tool”) (Clements et al. 2021)

This project aims to build upon and consolidate the ongoing research in the quantification and monetization of benefits of GSI by:

- Developing a user-friendly interactive guidebook with comparison case studies for utilities and municipalities to advance the quantification and monetization of benefits and co-benefits of GSI at the community level.
- Synthesizing comparison case studies that have used a rigorous analysis framework for quantifying the benefits and co-benefits of GSI at a national scale, including those from two existing WRF projects: Project 4798 (WRF, 2023) and Project 4852 (Clements et al. 2021).
- Advancing the practice of benefits and co-benefits quantification by identifying and prioritizing the research needs among GSI benefits and co-benefits categories.

Six case studies of varying scales, geographies, and storm sewer typologies were selected and run through CLASIC and the GSI TBL Tool to compare the outputs of each tool. This report summarizes all model inputs and outputs, recommendations for tool improvements, and areas for future research.

Benefits:

This project will advance the practice of benefits and co-benefits quantification by illustrating real-world examples of varying scales and geographies using the CLASIC and GSI TBL tools. Quantifying the benefits associated with GSI allows decision makers to justify the use of a balanced approach to stormwater management.

Keywords:

Benefits, Best Management Practice, Co-Benefits, Cost-Benefit Analysis, Green Stormwater Infrastructure, Lifecycle Cost, Stormwater Infrastructure, Stormwater Management, Triple Bottom Line

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Acronyms and Abbreviations

AVERT	Avoided Emissions and Generation Tool
BATT	Best Management Practice Accounting and Tracking Tool
BMP	Best Management Practice
CLASIC	Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs (Project 4798)
CSO	Combined Sewer Overflow
eGRID	Emissions and Generation Resource Integrated Database
EJ	Environmental Justice
EPA	Environmental Protection Agency
FIB	Fecal Indicator Bacteria
GIS	Geographic Information System
GSI	Green Stormwater Infrastructure
GSI TBL Tool	Economic Framework and Tools for Quantifying and Monetizing the Triple Bottom Line Benefits of Green Stormwater Infrastructure (Project 4852 / SIWM4T17)
MCDA	Multi-criteria Decision Analysis
MIDS	Minimal Impact Design Standards
MS4	Municipal Separate Storm Sewer Systems
NLCD	National Land Cover Database
O&M	Operations and Maintenance
PAC	Project Advisory Committee
SSURGO	Soil Survey Geographic Database
SWMM	Storm Water Management Model
TBL	Triple Bottom Line
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
US	United States
VELMA	Visualizing Ecosystem Land Management Assessments
VRRM	Virginia Runoff Reduction Method
WMOST	Watershed Management Optimization Support Tool
WRF	The Water Research Foundation

Executive Summary

ES.1 Overview of Project

The Water Research Foundation (WRF) previously funded two projects for evaluating benefits and co-benefits of green stormwater infrastructure (GSI):

- Community-enabled Lifecyle Analysis of Stormwater Infrastructure Costs (Project 4798), ("CLASIC") (WRF, 2023)
- Economic Framework and Tools for Quantifying and Monetizing the Triple Bottom Line Benefits of Green Stormwater Infrastructure (Project 4852 / SIWM4T17), ("GSI TBL Tool") (Clements et al. 2021)

The CLASIC tool is a cloud-based web screening tool that can be used to assess life-cycle costs, stormwater performance, and social and environmental benefits of GSI practices at the community, watershed, and neighborhood scales. A nominal level of stormwater and economic expertise is required to run and understand the tool. The expected users are consultants, academics, and managers and operators of regulated stormwater systems. Individuals with minimal knowledge of stormwater management design will likely need to spend additional time reviewing the user's manual or work with a water resources engineer. CLASIC can be used to compare and assess the effectiveness of different stormwater strategies and to evaluate regulatory compliance, runoff volume reduction, water quality, social and environmental benefits, and lifecycle costs. This tool is especially useful for determining planning level costs and for comparing various stormwater alternatives when detailed design information is not available.

The three main outputs from the CLASIC tool are lifecycle costs, co-benefits, and performance. The lifecycle cost provides feasibility-level municipal budget estimates over time for a variety of GSI construction and maintenance costs. A multi-criteria decision analysis (MCDA) informs the co-benefits analysis by providing a quantitative comparison across various scenarios. Performance scenarios are estimated through hydrologic (peak runoff and volume reduction) and pollutant load reduction metrics. It is noted that CLASIC is not meant for site-specific design of stormwater infrastructure, for comparison of spatial distribution within a project area, or to optimize a design. An in-depth overview for CLASIC can be found in Appendix B.

The GSI TBL tool is an excel-based tool that supports the quantification and monetization of environmental, social, and financial benefits of GSI at the community, watershed, or neighborhood scale. The GSI TBL tool requires expertise and familiarity with economics and GSI implementation and planning. It may be more appropriate for projects with a multi-disciplined team, including an engineer and economist.

Users are guided through a series of steps within the GSI TBL Tool to establish a scenario to model, define a baseline, and identify benefits within a triple bottom line framework. The tool estimates lifecycle cost and provides a summary of monetized community-level co-benefits. An in-depth overview for GSI TBL Tool can be found in Appendix C.

The CLASIC and GSI TBL Tool were built as stand-alone products. However, the GSI TBL Tool can leverage data and information from CLASIC to produce monetized co-benefits for GSI scenarios. This is especially useful for projects that are early in the planning process that don't have a defined stormwater approach yet. CLASIC can be used to produce the key design components (e.g., GSI system type, scale of implementation, and design criteria such as material depth and areas) that are required to run the GSI TBL Tool. If this design information is available, the GSI TBL Tool can be run without the use of CLASIC.

Six case studies of varying scales, geographies, and storm sewer typologies were selected and run through CLASIC and the GSI TBL Tool to compare the outputs of each tool. Case studies from the following locations were selected:

- Fort Collins, Colorado
- Philadelphia, Pennsylvania
- New Orleans, Louisiana
- Phoenix, Arizona
- San Antonio, Texas
- Sun Valley, California

Table ES-1 provides an overview of each case study including project location, US Climate Region, average annual precipitation, project drivers, key performance indicators, impervious area managed/treated, and GSI practices.

Table ES-1. Overview of Case Studies.

Project Location	Fort Collins, Colorado	Philadelphia, Pennsylvania	New Orleans, Louisiana	Phoenix, Arizona	San Antonio, Texas	Sun Valley, California
Detailed Case Study Chapter in Report	Chapter 2	Chapter 3	Chapter 4	Chapter 5	Chapter 6	Chapter 7
US Climate Region (NOAA, 1984)	Southwest	Northeast	South	Southwest	South	West
Average Annual Precipitation (Inches)	15.9	40.4	68.0	7.3	31.1	17.1
Project Driver(s)	Flood Risk Reduction and Water Quality	CSO Reduction	Flood Risk and Subsidence Reduction	Water Conservation and Urban Heat Island Reduction	Water Quality	Water Conservation and Urban Heat Island Reduction
Key Performance Indicator(s)	Volume of Water Treated and Percent Reduction in Pollutants	Volume of Water Treated	Volume of Water Treated and Increase in Green Space	Volume of Water Infiltrated and Increase in Green Space	Percent Reduction in Pollutants	Volume of Water Infiltrated and Increase in Green Space
Impervious Area Managed/ Treated (acres)	82.62	16.70	287.61	2.23	2.19	353.65
GSI Practices	Rain Gardens, Permeable Pavement, and Sand Filters	Rain Gardens and Subsurface Trenches	Rain Gardens and Wet Ponds	Rain Gardens and Permeable Pavement	Bioswales	Subsurface Trenches and Wet Ponds

ES.2 Research Approach

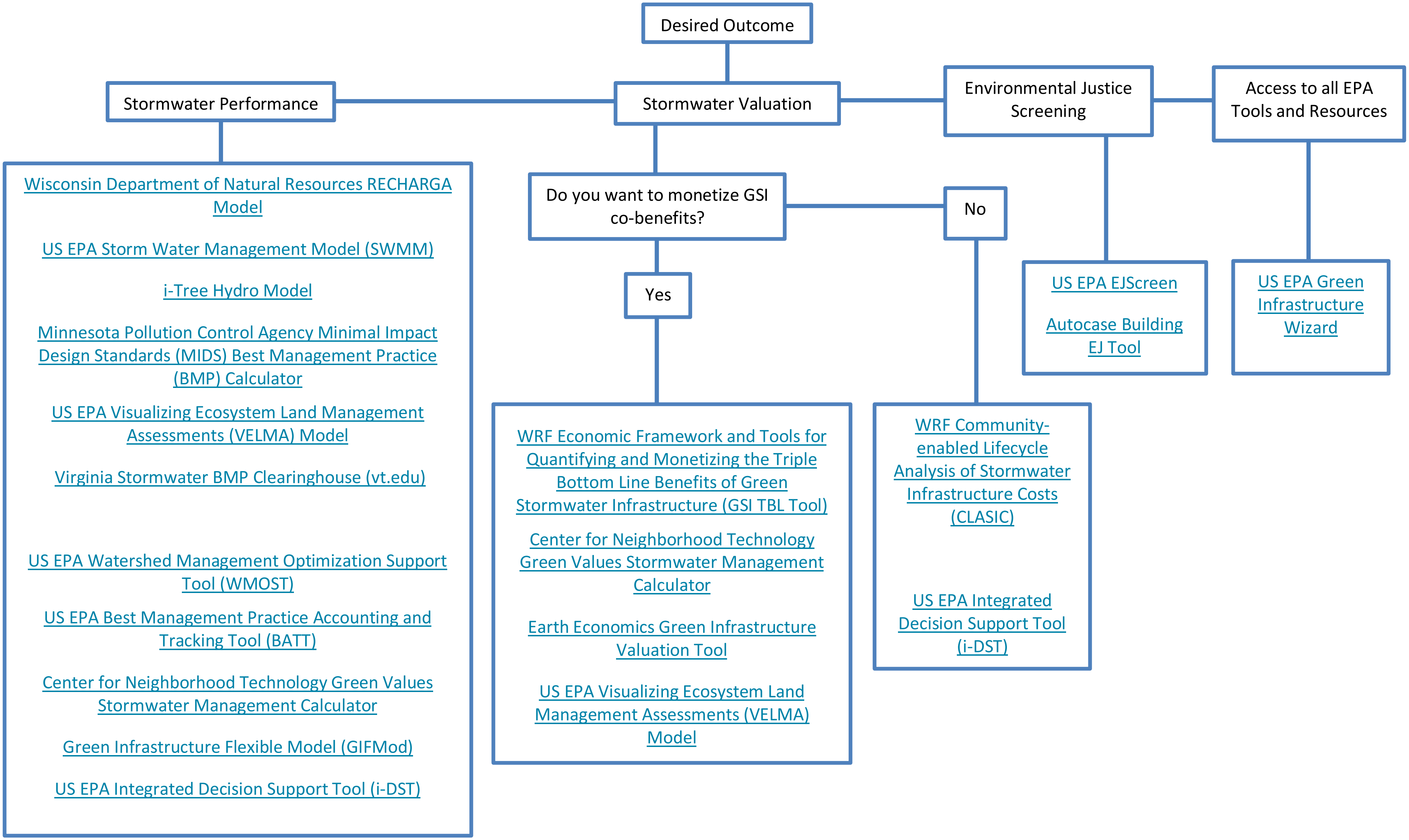
A variety of tools are available to support stormwater performance, valuation, and environmental justice screening. While not included in the case study comparison, the team performed research to identify available tools. Figure ES-1 is a decision matrix with links to the various tools. Additional information on these tools can be found in Appendix D.

Project details noted within this report were developed from a review of publicly available data and may not provide an accurate representation of the actual project. This information was used to provide a comparison of The Water Research Foundation's CLASIC and GSI TBL Tool outputs only and should not be relied upon for anything outside of the scope of this research project.

This report summarizes all model inputs and outputs, recommendations for tool improvements, and areas for future research. It should be noted that while CLASIC and the GSI TBL tools were not intended for site-specific design, the case studies range in scale from site-specific to watershed-based to test the models. Default values were assigned in the models to provide a direct comparison between case studies.

In many cases, detailed design parameters were adjusted from original designs to provide the best comparison between the two models. For example, GSI practices were modified when there wasn't an equivalent GSI practice in both tools (see Table 1-1). Comparison of Practices in CLASIC and GSI TBL Tool). Non-stormwater items were removed from the case studies since CLASIC does not account for these items. In addition, it was not possible to match drainage areas, volumes, and specific design details in both tools due to tool limitations and differences in the way specific design items are calculated. The team made a best effort to provide a true comparison within the limitations of the tools.

Figure ES-1. Overview of Stormwater Performance, Valuation, and Environmental Justice Screening Tools.



ES.3 Findings and Conclusions

Results of the case study comparison are provided in Table ES-2 through Table ES-4.

Table ES-2 provides a comparison of stormwater volume provided in the CLASIC and GSI TBL Tools. Stormwater volume is calculated differently in the tools. In CLASIC, stormwater volume is based on the surface area of the GSI practice and the depth available to store water in the ponding and filter media layers. A void space of 40% is assigned to open graded aggregate/stone and soil storage layers. In the GSI TBL Tool, stormwater volume is based on design depth to capture (feet) and impervious drainage area (square feet), with a factor of 0.98 applied. The GSI TBL Tool consistently provided slightly lower volumes due to the 0.98 factor.

The calculation for stormwater volume in permeable pavement systems accounted for the largest difference between the two tools. This is due to the minimum depth of stone required for pavement stability, which exceeded the design depth to capture in the case studies. In other words, permeable pavement systems can often handle a much larger storm event than the design depths attributed to GSI design.

Table ES-2. Comparison of Stormwater Volume Provided.

Case Study	Case Study Location	GSI Practices	CLASIC Tool Volume Provided (CF)	GSI TBL Tool Volume Provided (CF)
1	Fort Collins, Colorado	Rain Gardens, Permeable Pavement, Sand Filters	312,450	176,354
2	Philadelphia, Pennsylvania	Rain Gardens and Subsurface Trenches	62,400	59,409
3	New Orleans, Louisiana	Rain Gardens and Wet Ponds	10,413,200	10,115,218
4	Phoenix, Arizona	Rain Gardens and Permeable Pavement	23,264	7,930
5	San Antonio, Texas	Bioswales	9,300	7,791
6	Sun Valley, California	Subsurface Trenches and Wet Ponds	9,023,000	8,806,522

Table ES-3 provides a comparison of lifecycle costs provided in the CLASIC and GSI TBL Tool. Lifecycle costs are calculated as the total of construction costs, maintenance costs, and replacement costs over the lifetime of the asset, expressed as present value. Replacement costs are not automatically calculated for the GSI TBL Tool. For a more direct comparison, replacement costs and timelines were edited to match the outputs from the CLASIC tool.

The calculation for lifecycle cost of the wet ponds accounted for the largest difference between the two tools. This appears to be tied to a model calculation error within the GSI TBL Tool. The unit cost for the wet pond is noted as a cost per volume of $0.67/cubic foot on the Costs Timeline Tab. However, the lifecycle cost calculation appears to use the footprint instead of the volume in the lifecycle cost calculation. In addition, it is unclear if the wet pond calculation accounts for the cost of excavation for the permanent pool. As a result, case studies with a wet pond resulted in a significantly lower lifecycle cost.

Table ES-3. Comparison of Lifecycle Costs.

Case Study	Case Study Location	GSI Practices	CLASIC Tool Lifecycle Costs (US Dollars)	GSI TBL Tool Lifecycle Costs (US Dollars)
1	Fort Collins, Colorado	Rain Gardens, Permeable Pavement, and Sand Filters	$18,927,029	$17,849,628
2	Philadelphia, Pennsylvania	Rain Gardens and Subsurface Trenches	$3,019,056	$2,033,352
3	New Orleans, Louisiana	Rain Gardens and Wet Ponds	$27,878,751	$8,621,414
4	Phoenix, Arizona	Rain Gardens and Permeable Pavement	$1,050,682	$806,978
5	San Antonio, Texas	Bioswales	$674,868	$422,090
6	Sun Valley, California	Subsurface Trenches and Wet Ponds	$17,196,851	$5,861,875

Table ES-4 provides a comparison of co-benefit values in the CLASIC and GSI TBL Tool. In CLASIC, co-benefits are calculated as a relative score out of 15 based on user input as to the relevance and importance of various co-benefit categories. In the GSI TBL tool, co-benefits are monetized based on user input on the various co-benefit categories. The GSI TBL tool also provides a benefit-cost ratio in the results tab. The benefit-cost ratio describes the relationship between the relative benefits and costs of a proposed project, calculated as the monetized value of benefits over the lifecycle of the asset divided by lifecycle costs for the project. Projects with a benefit-cost ratio greater than 1.0 represent projects that have benefits that exceed the project costs and deliver a positive value to stakeholders.

While the relative co-benefit score in CLASIC is useful for comparing design alternatives, it has no correlation to the monetized co-benefit values and benefit-cost ratio provided in the GSI TBL Tool.

Table ES-4. Comparison of Co-Benefit Values.

Case Study	Case Study Location	GSI Practices	CLASIC Tool Co-Benefits Score (Out of 15)	GSI TBL Tool Co-Benefits Value (US Dollars)	GSI TBL Tool Benefit-Cost Ratio
1	Fort Collins, Colorado	Rain Gardens, Permeable Pavement, and Sand Filters	9.59	$6,328,634	0.35 : 1
2	Philadelphia, Pennsylvania	Rain Gardens and Subsurface Trenches	11.67	$2,308,128	1.14 : 1
3	New Orleans, Louisiana	Rain Gardens and Wet Ponds	6.46	$35,003,821	4.06 : 1
4	Phoenix, Arizona	Rain Gardens and Permeable Pavement	12.84	$476,089	0.59 : 1
5	San Antonio, Texas	Bioswales	11.41	$52,004	0.12 : 1
6	Sun Valley, California	Subsurface Trenches and Wet Ponds	2.65	$28,192,013	4.80 : 1

ES.3.1 CLASIC

CLASIC was found to be better suited for planning projects to compare the outcomes of various practices, scales, performances, and costs. CLASIC allows users to create up to three scenarios of various practices and scales within the same project boundary. This allows users to compare and develop a planning strategy around the right balance of green and gray practices, understand the scale of practices needed to meet various water quality and quantity performance measures, and the associated lifecycle costs for those alternatives.

CLASIC is a user-friendly tool that can be run without much training or support from engineers and economists. The tool is set up with a simple step-by-step process with pre-populated default values and drop-down menu options. The research team was able to develop scenarios within 30 minutes for each case study. For these reasons, CLASIC is recommended for a wider user base at the planning stage of projects.

In CLASIC, the model default is a “do nothing” case. This may be beneficial for users that simply want to compare design alternatives. Due to the limited number of stormwater practices (see Table 1-1), users may find it challenging to accurately capture a true baseline condition (e.g., what stormwater management or water quality measures would be required if the GSI project was not planned).

It was challenging to use CLASIC to model a project that was already designed since stormwater management features are added with pre-defined design features within drop-down menus. Modifications to the number of practices, drainage area captured, and volume provided was limited with the pre-defined design features. While there are ways to break down the overall project area with the use of subunits, it can be challenging to place the stormwater management features in a specific location within the project boundary. For this reason, CLASIC is not recommended for site-specific design.

Below are a few additional key takeaways from the project team’s experience with the CLASIC tool:

1. The team experienced challenges with making modifications to the pre-populated design criteria in CLASIC. While the tool allowed for customizing the number of practices and drainage area, such modifications often caused the tool to malfunction. Additional guidance or checks should be included in the model to avoid such malfunctions.
2. The CLASIC project output report is challenging to print and lacks detail that would be beneficial for users, including a breakdown of cost considerations and supporting calculations for water quality and quantity performance data.
3. The water quality and hydrologic performance outputs are presented as a percent reduction from baseline. The water quality pollutant load concentration input screen is listed as a concentration (mg/L). It would also be helpful to see water quality pollutant load reduction presented as an annual load (pounds/year). It would be helpful to see backup for these calculations. The project team was surprised by some of the results as noted in the key takeaway sections.
4. The CLASIC tool does not provide the ability to include additional costs for trees, parks, or other improvements that are non-stormwater related but could potentially have a significant impact on the project outputs.
5. More guidance should be incorporated into the co-benefits analysis and scoring system. It was challenging to identify the level of importance for each benefit category or to understand what types of improvements could be made to improve the score. If the project is not compared to another stormwater alternative within CLASIC, the co-benefit score does not appear to have much significance. It would be helpful to provide recommendations of which co-benefit categories may be important based on project location and drivers.
6. The CLASIC tool is a cloud-based tool that requires a unique password. The team experienced challenges with saving files and sharing this information across users, which may prove challenging for larger teams.

7. Once the project area is defined within CLASIC, it cannot be updated or modified without starting a new project file. This created some frustration with the project team.

ES.3.2 GSI TBL Tool

The GSI TBL Tool was found to be better suited for projects that were already in design where the stormwater management practices and associated design features have been determined. If this information is not available, the CLASIC tool could be used to generate this required stormwater management design criteria based on selections made with drop-down menus.

The GSI TBL Tool allows users to quantify and monetize various co-benefits associated with GSI, which is useful to demonstrate a project's value with a focus on the triple bottom line. The tool does a great job of taking difficult concepts and calculations and presenting this information in a spreadsheet format.

The GSI TBL Tool requires a more in-depth understanding of both engineering and economics principles to fill in the required fields. The multi-disciplined research team needed approximately 4–8 hours to complete the required fields for each case study analysis. For these reasons, the GSI TBL Tool is recommended for an integrated team of engineers and economists at the design stage of projects.

The GSI TBL Tool requires a deep understanding of the baseline case (e.g., what stormwater management or water quality measures would be required if the GSI project was not planned) since co-benefits are dependent on this information. For example, for communities with combined sewer overflows, the project baseline may include large-scale storage solutions or upgrades to a receiving wastewater treatment plant. For communities with water quality concerns, the project baseline may include large-scale water treatment solutions. For communities with water conservation goals, the baseline may include developing alternative water supply systems.

The co-benefits tabs within the tool present users with a series of questions to accurately calculate both the baseline scenario and the benefits of the GSI approach. The availability of this information may prove challenging to some users.

Below are a few additional key takeaways from the project team's experience with the GSI TBL Tool:

1. The GSI TBL Tool does not provide an analysis of water quality benefits. Water quality is a common project driver that allows capital improvement projects to be prioritized. Without some level of detail provided in the tool, a user cannot understand if projects meet local requirements.
2. The GSI TBL does not provide the ability to include additional costs for parks or other improvements that are non-stormwater related.
3. More background information could be provided to support the project costs with an option to make modifications to meet current cost trends.

4. The GSI TBL tool project output report is challenging to print. It would be helpful to have a summary chart for sharing information.
5. The case studies all resulted in no energy savings benefits, heat stress credits, or water quality improvement values.

ES.3.3 Both Tools

1. The team identified a few calculation errors (see APPENDIX_F) that should be resolved with future model updates.
2. The team recommends updating the CLASIC and GSI TBL tools to make them more complimentary with one another. This could be accomplished by ensuring that the stormwater management practices, design terminologies, and calculations are consistent. In addition, it would be a big improvement if outputs from CLASIC could be automatically uploaded into the GSI TBL tool to streamline the analysis.
3. The team recommends incorporating an environmental equity and social justice lens into both tools.
4. The team recommends updates to the user manuals of both CLASIC and the GSI TBL Tool to include comparisons of the practices within the tools.
5. Both tools are run with the assumption that practices are independent of one another and receive a distinct drainage area. The tools could benefit from including options for a treatment train approach, as this is common for stormwater management systems.
6. The tools do not seem to account for other factors that impact GSI performance, such as geotechnical conditions, storm duration and intensity, and how GSI systems are connected (e.g., some systems may be in series).

Table ES-5 provides a tool overview comparison with user experience, inputs, and outputs of each tool.

Table ES-5. WRF Tool Overview Comparison.

Description	CLASIC Tool	GSI TBL Tool
User Experience		
Cloud Based Tool	☑	☒
Excel Based Tool	☒	☑
Includes Regional Cost Adjustment Factors	☑	☑
Ability to Adjust Unit Cost Data	☑	☑
Ability to Compare Multiple Design Scenarios	☑	☒
Time Commitment of 30 Minutes or Less	☑	☒
Tool Inputs		
Applicable for Planning Projects (Minimum Input is Project Location, Stormwater Management Type(s), and Relative Scale of Implementation)	☑	☒
Applicable for Design Projects (Minimum Input is Project Location, Stormwater Management Type(s), and Detailed Stormwater Design Parameters including design footprint, depth, and porosity)	☒	☑

Description	CLASIC Tool	GSI TBL Tool
Ability to Set and Confirm Compliance with Water Quality Targets	☑	☒
Ability to Adjust Future Land Use and Climate Change Scenarios	☑	☒
Can be Used for Site-Specific Design	☒	☒
Can be Used for Neighborhood and Watershed Scale Analysis	☑	☑
Outputs		
Lifecycle Costs	☑	☑
Relative Scoring System for Co-Benefits (Rated on Scale of 1 – 15)	☑	☒
Monetized Co-Benefits	☒	☑
Quantification of Water Quality Load Reductions	☑	☒
Quantification of Flood Reduction Benefits	☒	☒
Quantification of Environmental Justice and Social Equity Considerations	☒	☒

ES.4 Recommendations for Tool Enhancement

Below are some suggestions for potential improvements for the CLASIC and GSI TBL Tool. These suggestions are the result of the team running the Case Studies and comparing the models. Some of these suggestions are more critical if trying to use the tools together for comparison, such as keeping terminology, significant digits, and units consistent for GSI practice inputs.

Comparing the two tools was challenging since the tools use different design parameters, GSI practices, and naming conventions. Table ES-6 provides a comparison of design terminology in the tools.

Table ES-6. Comparison of Design Terminology.

CLASIC	GSI TBL Tool
Average annual runoff	Annual runoff that results in runoff
Annual discount factor	Discount rate
Project boundary	Management area
Depth to capture	Design storm depth
Practices	BMPs
Total captured area	Effective impervious area managed
Total volume captured	Volume capacity by BMP type
Surface area	BMP size
Filter media depth	Depth
Total volume captured	Volume capacity by BMP

As a general recommendation for both tools, both the CLASIC & GSI Co-Benefits tools are reliant upon the design solutions provided by the user, and don’t provide their own suggestions to optimize the project. Machine learning processes could run iterative calculations based on project characteristics, design recommendations and resource constraints, and provide solutions unknown to the user that would maximize a project’s performance. There could be opportunities to integrate the tools with algorithmic functions or third-party GSI design software add-ons that rely on machine learning and artificial intelligence principles to increase a project’s efficiency given a certain set of parameters. There is existing academic literature on the topic; for example, there are studies that use machine learning methods to simulate precipitation runoff, or forecast hydrological responses to urban drainage systems, among other applications.

An additional recommendation for both tools is the addition of disservices related to the projects. This could include construction-related disruptions or a reduction in public parking near businesses.

ES.4.1 CLASIC

1. The team recommends providing clear and concise definitions of each design input/parameter with equations for clarity.
2. The co-benefits section should be automatically completed based on project drivers and input rather than having the user select the level of importance. As an alternative, the tool could be modified to provide more information about selecting the importance of each factor. More input should be given about understanding the co-benefits score when there is not a comparison scenario.
3. The team recommends including a hint about keeping file names short and not including symbols within the file name. The project team had files disappear after spending a significant amount of time developing the case study from incorrect file naming conventions.
4. The team experienced a significant number of errors when first developing the case studies where the team was not able to run the model or view results. It is believed that these errors were caused from modifications to the editable design parameters on the right side of the screen. More research should be invested into the tool functionality.
5. The team recommends allowing GSI practices to be routed in series.
6. The team recommends providing a unit cost table for practices, and classes within practices, to be more transparent about default values. This will allow users a better understanding of when default values do not align with local information.
7. The team recommends summarizing all calculations used in each tool within the user manual. Based on the nature of the tool, users should be able to see how a value is calculated, even if they can't manipulate the input values. Very few calculations are currently provided in the manual.
8. The project team found it challenging to draw in the project area to match the case studies since they didn't have a GIS shapefile. In addition, the project area seemed to disappear from the screen after the linework was drawn. This was a parameter that was used in the GSI TBL Tool, so the team found it frustrating that the project area was not included in the output file. In addition, once the project area is chosen, it can't be edited without starting a new project.
9. CLASIC does not allow for adjustments to subunits after one option is chosen without starting a new project. The project team explored a variety of subunits for each project, and ultimately used a single subunit for each case study as that resulted in the simplest comparison and shortest model run. This is particularly important for using as a planning tool. Users will have a desire to compare multiple areas/scenarios in a time-efficient manner.
10. CLASIC has limits for the design storm depth (10 inches) and seepage rate (5 inches per hour). These limits may be a limiting factor on projects, such as the Sun Valley case study.

11. The team recommends amending the water quality load reductions to include calculation of the loading in terms of pounds per year as well as of percentage reductions. Similarly, the water performance results should be calculated as volume per year as well as percentage reductions.
12. The team recommends providing an input option for additional costs that are not part of the stormwater GSI practice, such as the cost for routing new storm drainage or pump stations.
13. The team recommends updates to the project report summary so that project inputs and outputs are clearly stated and summarized.
14. The team recommends providing a breakdown of cost, hydrology, and water quality values per GSI practice so that the results can provide better insight.
15. The team recommends adding more GSI practices.
16. Water quality pollutant list should be updated to include Chloride.
17. The team recommends including for options for separate sewer communities such as avoided potable water costs for irrigation.

ES.4.2 GSI TBL Tool

1. The team recommends providing clear and concise definitions of each design input/parameter with equations for clarity.
2. The user manual hints that outputs from CLASIC can be input into the GSI TBL Tool. The project team did not find this to be an easy process since there are differences in terminology and project approaches. If the intent is for the tools to be used together, the outputs from CLASIC and the inputs from the GSI TBL Tool should be synched in a way that allows for an easier way to input the data.
3. The team recommends including replacement costs as automatic calculations. It was challenging to match the outputs from CLASIC.
4. The team recommends allowing GSI practices to be routed in series.
5. The team recommends providing guidance for acceptable run-on-ratios for various practices as a potential design check.
6. The team recommends allowing for modifications to the design storm per GSI practice instead of per project.
7. The team recommends providing more guidance on design storm percentile as this was not always a known parameter.
8. The team recommends additional research for GSI practice cost as the ranges provided were too varied, even when taking into account economy of scale.
9. The team recommends adding more GSI practices, especially for separate sewer systems.
10. The team recommends providing an input option for additional costs that are not part of the stormwater GSI practice, such as the cost for routing new storm drainage or pump stations.
11. The team recommends providing outputs in the form of pounds removed (or similar unit) in addition to mg/L to account for differences in water quality standards across states.

12. Water quality pollutants should be updated to include total suspended solids (TSS), total phosphorus (TP), total nitrogen (TN), e. Coli, and Chloride.
13. The team recommends determining why the volume provided for permeable pavement varies significantly from the volume provided in CLASIC.
14. The team recommends including options for separate sewer communities such as avoided potable water costs for irrigation.
15. The team recommends including more backup for design calculations. There is concern that some of the benefits may be inflated if the user is not clear on inputs.
16. The team recommends including clarification on the job creation credit and explaining if it accounts for another gray job that is not being used.

ES. 5 Related WRF Research

- Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs (CLASIC) (4798-4804)
- Economic Framework and Tools for Quantifying and Monetizing the Triple Bottom Line Benefits of Green Stormwater Infrastructure (4852)
- Assessing the State of Knowledge and Research Needs for Stormwater Harvesting (4841)
- Enhancement of Resilience to Extreme Weather and Climate Events: Proactive Flood Management (4842)
- Holistic Approaches to Flood Mitigation Planning and Modeling under Extreme Events and Climate Impacts (5084)
- Diversifying Water Portfolios through Stormwater Capture and Use: Contributing to a Water Resilient Future (5236)

CHAPTER 1

Introduction

1.1 Overview

Chapter 1 is an introduction to the research project. Chapter 1 provides an overview of the project background, discussion of the CLASIC and GSI TBL tools which are the focus of this project, project scope of work, and case study selection. This chapter also includes an overview of the report layout and quick reference guide with links to various sections of the report.

1.2 Project Background

As the world faces ever-increasing community challenges associated with climate change and water quality standards, the role and importance of green stormwater infrastructure (GSI) is expanding. GSI can be used to enhance recreation and quality of life, reduce the effects of excessive heat and the urban heat island effect, improve air quality and habitats, offset climate change, and restore ecosystems. In addition, GSI can be used to reduce operational costs for stormwater management, reduce nuisance flooding, reduce irrigation needs, increase property values, and create long-lasting jobs for the local economy. GSI is an equitable approach for wet weather impacts because it is a tool that can mitigate situations that tend to disproportionately impact disadvantaged areas of a community, such as urban heat stress. For these reasons, many utilities and municipalities have explored the use of GSI as a cost-effective way to build resilience into their systems while providing benefits and co-benefits to its users.

Quantifying benefits attributable to GSI systems provides utilities and municipalities with a holistic view in evaluating future stormwater investments. Conventional cost analyses for such comparisons typically include a review of initial capital costs (e.g., planning, design, and construction) and lifecycle costs (e.g., operation and maintenance, replacement costs, and end of life costs). However, this approach is limited as it does not account for the full range of benefits that can be achieved with GSI, and therefore does not provide an accurate basis for reviewing design alternatives. For this reason, gray infrastructure may appear more cost-effective than GSI.

Conversely, a triple bottom line cost-benefit analysis quantifies and monetizes the costs and benefits (or disbenefits, as appropriate) of employing design alternatives with a focus on financial, social, and environmental outcomes. This approach ensures that holistic costs and benefits of each alternative are presented to the decision makers, and ultimately allows for better and more complete decisions to be made with limited resources.

The Water Research Foundation (WRF) previously funded two projects for evaluating benefits and co-benefits of GSI:

- Community-enabled Lifecyle Analysis of Stormwater Infrastructure Costs (Project 4798), (“CLASIC”) (WRF, 2023)

- Economic Framework and Tools for Quantifying and Monetizing the Triple Bottom Line Benefits of Green Stormwater Infrastructure (Project 4852 / SIWM4T17), ("GSI TBL Tool") (Clements et al. 2021)

1.3 CLASIC and GSI TBL Tool Overview

The CLASIC tool is a cloud-based web screening tool that can be used to assess life-cycle costs, stormwater performance, and social and environmental benefits of GSI practices at the community, watershed, and neighborhood scales. A nominal level of stormwater and economic expertise is required to run and understand the tool. The expected users are consultants, academics, and managers and operators of regulated stormwater systems. Individuals with minimal knowledge of stormwater management design will likely need to spend additional time reviewing the user's manual or work with a water resources engineer. CLASIC can be used to compare and assess the effectiveness of different stormwater strategies and to evaluate regulatory compliance, runoff volume reduction, water quality, social and environmental benefits, and lifecycle costs. This tool is especially useful for determining planning level costs and for comparing various stormwater alternatives when detailed design information is not available.

The three main outputs from the CLASIC tool are lifecycle costs, co-benefits, and performance. The lifecycle cost provides feasibility-level municipal budget estimates over time for a variety of GSI construction and maintenance costs. A multi-criteria decision analysis (MCDA) informs the co-benefits analysis by providing a quantitative comparison across various scenarios. Performance scenarios are estimated through hydrologic (peak runoff and volume reduction) and pollutant load reduction metrics. It is noted that CLASIC is not meant for site-specific design of stormwater infrastructure, for comparison of spatial distribution within a project area, or to optimize a design. An in-depth overview for CLASIC can be found in Appendix B.

The GSI TBL tool is an excel-based tool that supports the quantification and monetization of environmental, social, and financial benefits of GSI at the community, watershed, or neighborhood scale. The GSI TBL tool requires expertise and familiarity with economics and GSI implementation and planning. It may be more appropriate for projects with a multi-disciplined team, including an engineer and economist.

Users are guided through a series of steps within the GSI TBL Tool to establish a scenario to model, define a baseline, and identify benefits within a triple bottom line framework. The tool estimates lifecycle cost and provides a summary of monetized community-level co-benefits. An in-depth overview for GSI TBL Tool can be found in Appendix C.

The CLASIC and GSI TBL Tool were built as stand-alone products. However, the GSI TBL Tool can leverage data and information from CLASIC to produce monetized co-benefits for GSI scenarios. This is especially useful for projects that are early in the planning process that don't have a defined stormwater approach yet. CLASIC can be used to produce the key design components (e.g., GSI system type, scale of implementation, and design criteria such as material depth and areas) that are required to run the GSI TBL Tool. If this design information is available, the GSI TBL Tool can be run without the use of CLASIC.

Both tools are available through the WRF website using a "public plus" free membership. Table 1-1 provides a comparison of available GSI practices in each tool. As noted in the case studies, the team made modifications to the GSI designs to provide a case study comparison as the tools do not include the same practices.

Table 1-1. Comparison of Practices in CLASIC and GSI TBL Tool.

GSI TBL Tool Practices	CLASIC Practices
Rain Gardens	Rain Garden
Bioretention Facilities	Infiltration Trench
Green Roofs	Green Roof
Tree Planting / Street Trees	Not Included in CLASIC
Permeable Pavement	Permeable Pavement
Cisterns – Rainwater Harvesting	Stormwater Harvesting
Rain Barrels – Rainwater Harvesting	Stormwater Harvesting
Constructed Wetland	Not Included in CLASIC
Wet Ponds	Wet Pond
Biofiltration / Grass or Vegetated Swale	Not Included in CLASIC
Not Included in GSI TBL Tool	Sand Filter
Not Included in GSI TBL Tool	Detention Basin
Not Included in GSI TBL Tool	Storage Vault
Not Included in GSI TBL Tool	Disconnection

1.4 Scope of Work

This project aims to build upon and consolidate the ongoing research in the quantification and monetization of benefits of GSI by:

- Developing a user-friendly interactive guidebook with comparison case studies for utilities and municipalities to advance the quantification and monetization of benefits and co-benefits of GSI at the community level.

- Synthesizing comparison case studies that have used a rigorous analysis framework for quantifying the benefits and co-benefits of GSI at a national scale, including those from two existing WRF projects: Project 4798 (WRF, 2023) and Project 4852 (Clements, 2021).
- Advancing the practice of benefits and co-benefits quantification by identifying and prioritizing the research needs among GSI benefits and co-benefits categories.

Six case studies of varying scales, geographies, and storm sewer typologies were selected and run through CLASIC and the GSI TBL Tool to compare the outputs of each tool. This report summarizes all model inputs and outputs, recommendations for tool improvements, and areas for future research.

This project will advance the practice of benefits and co-benefits quantification by illustrating real-world examples of varying scales and geographies using the CLASIC and GSI TBL tools. Quantifying the benefits associated with GSI allows decision makers to justify the use of a balanced approach to stormwater management.

1.5 Case Study Selection

Six case studies of varying scales, geographies, and storm sewer typologies were selected and run through CLASIC and the GSI TBL Tool to compare the outputs of each tool. Case studies from the following locations were selected:

- Fort Collins, Colorado
- Philadelphia, Pennsylvania
- New Orleans, Louisiana
- Phoenix, Arizona
- San Antonio, Texas
- Sun Valley, California

Table 1-2 provides an overview of each case study including project location, US Climate Region, average annual precipitation, project drivers, key performance indicators, impervious area managed/treated, and GSI practices.

Table 1-2. Overview of Case Studies.

Project Location	Fort Collins, Colorado	Philadelphia, Pennsylvania	New Orleans, Louisiana	Phoenix, Arizona	San Antonio, Texas	Sun Valley, California
Detailed Case Study Chapter in Report	Chapter 2	Chapter 3	Chapter 4	Chapter 5	Chapter 6	Chapter 7
US Climate Region (NOAA, 1984)	Southwest	Northeast	South	Southwest	South	West
Average Annual Precipitation (Inches)	15.9	40.4	68.0	7.3	31.1	17.1
Project Driver(s)	Flood Risk Reduction and Water Quality	CSO Reduction	Flood Risk and Subsidence Reduction	Water Conservation, Urban Heat Island Reduction	Water Quality	Water Conservation, Urban Heat Island Reduction
Key Performance Indicator(s)	Volume of Water Treated, Percent Reduction in Pollutants	Volume of Water Treated	Volume of Water Treated, Increase in Green Space	Volume of Water Infiltrated, Increase in Green Space	Percent Reduction in Pollutants	Volume of Water Infiltrated, Increase in Green Space
Impervious Area Managed/ Treated (acres)	82.62	16.70	287.61	2.23	2.19	353.65
GSI Practices	Rain Gardens, Permeable Pavement, Sand Filters	Rain Gardens and Subsurface Trenches	Rain Gardens and Wet Ponds	Rain Gardens and Permeable Pavement	Bioswales	Subsurface Trenches and Wet Ponds

1.6 Research Approach

Project details noted within this report were developed from a review of publicly available data and may not provide an accurate representation of the actual project. This information was used to provide a comparison of WRF's CLASIC and GSI TBL Tool outputs only and should not be relied upon for anything outside of the scope of this research project.

This report summarizes all model inputs and outputs, recommendations for tool improvements, and areas for future research. It should be noted that while CLASIC and the GSI TBL tools were not intended for site-specific design, the case studies range in scale from site-specific to watershed-based to test the models. Default values were assigned in the models to provide a direct comparison between case studies.

In many cases, detailed design parameters were adjusted from original designs to provide the best comparison between the two models. For example, GSI practices were adjusted when there wasn't an equivalent GSI practice in both tools. Non-stormwater items were removed from the case studies since CLASIC does not account for these items. In addition, it was not possible to match study areas, drainage areas, volumes, and specific design details in both tools due to limitations within the tools and differences in the way specific design items are calculated within each tool. The team made their best effort to provide a true comparison within the limits of the tools.

1.7 Overview of Report Layout

Table 1-3 is an overview of each chapter and appendix within the report.

Table 1-3. Overview of Report Layout.

Report Section	Description
Chapter 1	Brief overview of the research project background, purpose and goals, research approach, and case studies
Chapter 2 Chapter 3 Chapter 4 Chapter 5 Chapter 6 Chapter 7	Detailed review of case studies 1 through 6 including project descriptions, tool inputs, tool outputs, and key takeaways
Chapter 8	Summary of project conclusions, recommendations for tool updates, research gaps, and area for future research
Appendix A	Brief overview of triple bottom line cost-benefit analysis process, categories, inputs, and outcomes

Report Section	Description
Appendix B	Detailed review of WRF CLASIC with simplified user manual
Appendix C	Detailed review of WRF GSI TBL Tool with simplified user manual
Appendix D	Listing of other tools for evaluating stormwater performance, valuations, and environmental justice screening
Appendix E	Listing of recommendations for future research and tool updates
Appendix F	Matrix for determination of appropriate tool(s)

1.8 Quick Reference Guide

Table 1-4 is a quick reference guide on where to find relevant information in the report based on user interests and needs.

Table 1-4. Quick Reference Guide.

I Am Interested in Learning More About…	Relevant Section of Report
Triple Bottom Line Cost-Benefit Analysis	Appendix A
GSI Co-Benefit Categories	Appendix A.2
GSI Project Drivers and Key Performance Indicators	Appendix A.3
CLASIC Tool	Appendix B
WRF TBL Tool	Appendix C
Other Stormwater BMP Performance and Valuation Tools	Appendix D
Recommendations for Future Updates and Research	Appendix E
Recommendations for Tools	Appendix F
Combined Sewer Overflow Reduction	Chapter 3 (case study)
Flood Risk Reduction	Chapter 2 (case study) Chapter 4 (case study)
Water Quality	Chapter 2 (case study) Chapter 6 (case study)

I Am Interested in Learning More About…	Relevant Section of Report
Water Conservation	Chapter 5 (case study) Chapter 7 (case study)
Urban Heat Island Reduction	Chapter 5 (case study) Chapter 7 (case study)

CHAPTER 2

Case Study #1: Fort Collins, Colorado

2.1 Overview

This case study highlights a project in Fort Collins, Colorado in the Southwest Climate Region. The key project drivers are flood risk reduction and water quality improvements. The case study includes the use of rain gardens, permeable pavement, and sand filters to manage 82.62 acres of impervious cover.

2.2 Background

Fort Collins, Colorado is situated along the Colorado Front Range, approximately 60 miles north of Denver. The city is approximately 57 square miles and is comprised primarily of urban and suburban neighborhoods. Cache La Poudre River, mostly fed by snowmelt from the mountains, intersects the city from the northwest to the southeast.

The study area is within the downtown area of Fort Collins, an area that experiences frequent flooding and water quality issues. Flooding in the downtown area is likely due to a combination of the Cache La Poudre River transitioning from a steep gradient in the mountains to an incised channel with minimal floodplain banks as it travels through the city as well as undersized storm sewer systems.

Fort Collins receives approximately 16 inches of precipitation each year and approximately 51 inches of snowfall. Proper management of stormwater is critical to protect the region from flooding and to improve water quality. This case study explores the hypothetical use of distributed GSI systems to reduce street flooding, improve green space, and review ways to incorporate different stormwater GSI practices in a highly urbanized area.

Key model inputs are summarized in Table 2-1. This case study was modeled from the Fort Collins Case Study on the CLASIC website, specifically Scenario 2. Where information was not clearly stated in the Case Study, assumptions were made and are noted below.

Table 2-1. Fort Collins, CO – Key Model Inputs.

Feature	Value	Unit of Measurement
Average Annual Precipitation	15.9	Inches
Average Annual Runoff (CLASIC) or Annual Rainfall that Results in Runoff (GSI TBL Tool)	5.2	Inches
Cost Regionalization Factor	1	%
Annual Discount Factor (CLASIC) or Discount Rate (GSI TBL Tool)	0	%
Analysis Period	35	Years

An overview of the stormwater management approach is summarized in Table 2-2.

Table 2-2. Fort Collins, CO – Design Overview.

Design Parameter	Permeable Pavers	Rain Garden	Sand Filter
Impervious Drainage Area (Acres)	13.81	41.49	27.32
Impervious Drainage Area (Square Feet)	601,564	1,807,304	1,190,059
Proposed BMP Footprint (Square Feet)	601,689	57,000	38,000
Proposed Surface Storage Depth (Feet) [100% Porosity]	0	1	1
Proposed Subsurface Storage Depth (Feet) [40% Porosity]	0.67	1.5	1.5
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool) (Feet)	0.05	0.05	0.05
Volume Required (CF)	30,078	90,365	59,503
Volume Provided (CF)	160,450	91,200	60,800

As illustrated in Table 2-2, the permeable pavers are expected to provide a much greater storage volume than required. This is due to the amount of subsurface stone storage that is required for structural stability of the pavement system.

2.3 CLASIC Model Overview

CLASIC includes icons on the left side of the screen to guide the user through the steps of the CLASIC Tool. Inputs for this case study have been presented in the same order as the CLASIC guide for ease of review.

2.3.1 Define Study Area

A rectangular-shaped area was selected for downtown Fort Collins using the draw on map function. This case study was run with a single subunit. Figure 2-1 illustrates the proposed project boundary.

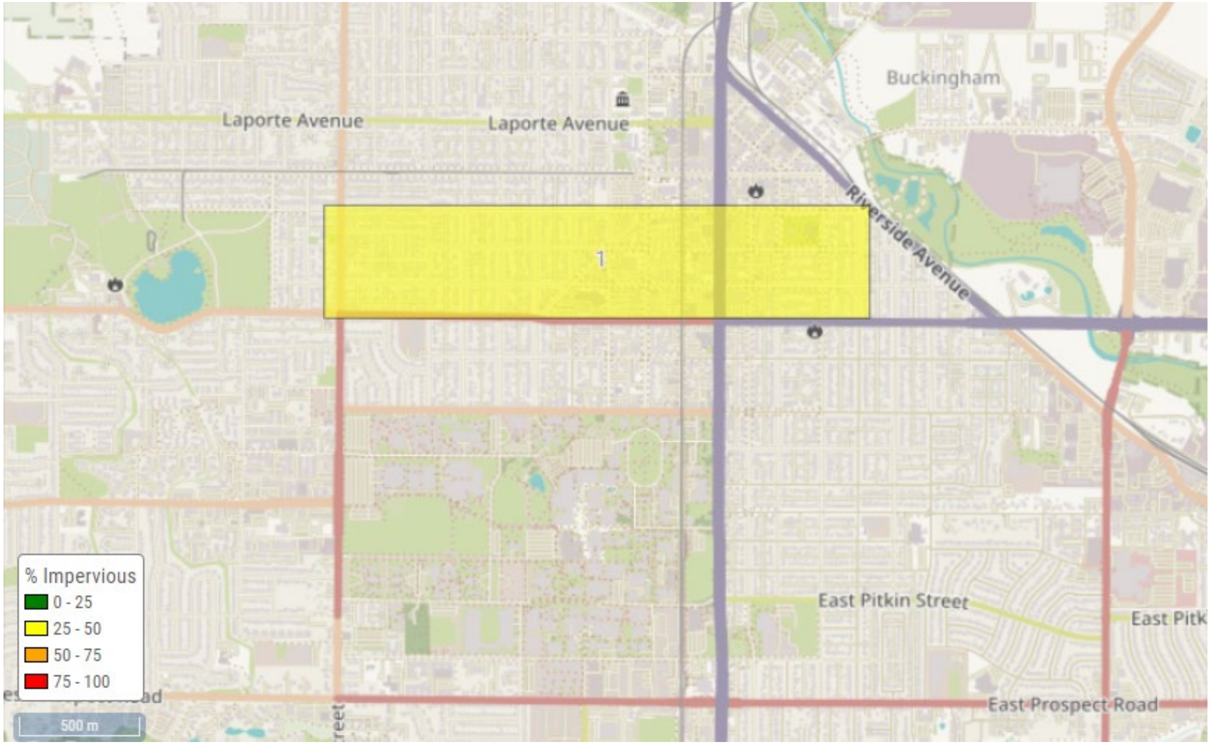
2.3.2 Select Climate Data

The Fort Collins precipitation and evaporation stations were chosen.

2.3.3 Define Model Defaults

No modifications were made to the model default values.

Figure 2-1. Fort Collins, CO – Project Overview.



2.3.4 Build Scenarios

The permeable pavement, rain garden, and sand filter GSI practices were used for this case study. Design parameters are summarized in Table 2-3 through Table 2-5.

Table 2-3. Fort Collins, CO – CLASIC Model Design Parameters – Permeable Pavement.

Design Parameter	Unit	Unit of Measurement
Pavement Material	Pavers	Unitless
Run-on-Ratio	0:01	Unitless
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	0.6	Inches
Storage Depth	8	Inches
Number of Practices (CLASIC) / Number of BMPs (GSI TBL Tool)	1	Unitless
Total Captured [Impervious] Area (CLASIC) / Effective Impervious Area Managed (GSI TBL Tool)	13.81	Acres
Total Technology Area (CLASIC) / Calculated BMP Area (GSI TBL Tool)	601,689	SF
Total Volume Captured (CLASIC) / Volume Capacity by BMP Type (GSI TBL Tool)	160,450	CF
Years to Replacement	35	Years

Table 2-4. Fort Collins, CO – CLASIC Model Design Parameters – Rain Garden.

Design Parameter	Unit	Unit of Measurement
Class	Medium	Unitless
Surface Area (CLASIC) / BMP Size (GSI TBL Tool)	1,000	SF
Ponding Depth	12	Inches
Filter Media Depth (CLASIC) / Depth (GSI TBL Tool)	18	Inches

Design Parameter	Unit	Unit of Measurement
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	0.6	Inches
Number of Practices (CLASIC) / Number of BMPs (GSI TBL Tool)	57	Unitless
Total Captured [Impervious] Area (CLASIC) / Effective Impervious Area Managed (GSI TBL Tool)	41.49	Acres
Total Technology Area (CLASIC) / Calculated BMP Area (GSI TBL Tool)	57,000	SF
Total Volume Captured (CLASIC) / Volume Capacity by BMP Type (GSI TBL Tool)	91,200	CF
Years to Replacement	25	Years

Table 2-5. Fort Collins, CO – CLASIC Model Design Parameters – Sand Filter.

Design Parameter	Unit	Unit of Measurement
Class	Medium	Unitless
Surface Area	1,000	SF
Ponding Depth	12	Inches
Filter Media Depth (CLASIC) / Depth (GSI TBL Tool)	18	Inches
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	0.6	Inches
Number of Practices (CLASIC) / Calculated BMP Area (GSI TBL Tool)	38	Unitless
Total Captured [Impervious] Area (CLASIC) / Effective Impervious Area Managed (GSI TBL Tool)	27.32	Acres
Total Technology Area (CLASIC) / Calculated BMP Area (GSI TBL Tool)	38,000	SF

Design Parameter	Unit	Unit of Measurement
Total Volume Captured (CLASIC) / Volume Capacity by BMP Type (GSI TBL Tool)	60,800	CF
Years to Replacement	25	Years

2.3.5 Set Importance of Co-Benefits

Table 2-6 highlights the co-benefit factors that were identified as significant for this project. Inputs in this tab are used to develop the co-benefit analysis score. Please note that the assigned level of importance was developed by the research team based on their understanding of the project and tool inputs.

Table 2-6. Fort Collins, CO – CLASIC Model Co-Benefit Analysis Importance Factors.

Co-Benefit Category	Co-Benefit	CLASIC Parameter Used for Estimation	Assigned Level of Importance
Financial	Increased Property Values	Reduction in Impervious Cover / Increase in Green Space	Medium Importance
Financial	Reduced Costs from Illness	Increase in Plants, Trees, and Green Roofs	Somewhat Important
Financial	Avoided Costs from Combined Sewer Treatment	Combined Sewer Systems Only; Runoff Volume Reduction	Not Important
Financial	Reduced or Mitigated Impacts from Nuisance Floods	Runoff Volume Reduction	Very Important
Financial	Enhanced Building Energy Efficiency	Area of Green Roof	Not Important
Financial	Avoided Water Treatment	Volume of Stormwater Harvested	Not Important
Financial	Improvements to Employment Opportunities	Annual Maintenance Cost	Medium Importance

Co-Benefit Category	Co-Benefit	CLASIC Parameter Used for Estimation	Assigned Level of Importance
Social	Health Benefits from Improvements to Air Quality	Increase in Plants, Trees, and Green Roofs	Somewhat Important
Social	Mental Health Improvements	Reduction in Impervious Cover / Increase in Green Space	Somewhat Important
Social	Improvements to Thermal Health	Reduction in Impervious Cover / Increase in Green Space	Somewhat Important
Social	Increased Supply from Harvested Stormwater	Volume of Stormwater Harvested	Not Important
Social	Increased Public Awareness of Stormwater and Water Systems	Number of GSI Practices	Very Important
Social	Potential Avoided Social Strain Associated with Nuisance Flooding	Runoff Volume Reduction	Very Important
Environmental	Improvements to Ecosystem Services	Diversity of Vegetation	Somewhat Important
Environmental	Increased Groundwater Flow	Runoff Volume Infiltrated	Very Important
Environmental	Carbon Sequestration	Increase in Plants, Trees, and Green Roofs	Somewhat Important

2.3.6 Set Targets

Targets were not included in the case study.

2.3.7 Results

A baseline scenario was not developed for this case study. Therefore, results will be compared to a “do nothing” scenario. Results are presented as Table 2-7 through Table 2-11.

Table 2-7. Fort Collins, CO – CLASIC Model Results: Volume.

Stormwater GSI Practice	Volume Required (CF)	Volume Provided (CF)
Permeable Pavement	30,078	160,450
Rain Garden	90,365	91,200
Sand Filter	59,503	60,800
Total	**179,946**	**312,450**

Table 2-8. Fort Collins, CO – CLASIC Model Results: Lifecycle Costs.

Description	Present Value Cost (US Dollars)
Construction Cost	$ 9,829,008
Maintenance Cost	$ 4,448,447
Replacement Cost	$ 4,649,574
Total Lifecycle Cost	**$ 18,927,029**

Table 2-9. Fort Collins, CO – CLASIC Model Results: Co-Benefits.

Description	Co-Benefit Score (Out of 5 Each or 15 Total)
Social Benefits Score	4.00
Economic Score	2.67
Environmental Score	2.92
Total Score	**9.59**

Table 2-10. Fort Collins, CO – CLASIC Model Results: Hydrologic Performance.

Description	Percentage Change from Baseline
Average Annual Runoff (Inches)	64.2% Reduction
Average Annual Infiltration (Inches)	34.2% Increase
Average Annual Evaporation (Inches)	3.6% Increase

Table 2-11. Fort Collins, CO – CLASIC Model Results: Water Quality Performance.

Description	Percentage Change from Baseline
Total Suspended Solids	64.2% Reduction
Total Nitrogen	64.2% Reduction
Total Phosphorus	64.2% Reduction
Fecal Indicator Bacteria	64.2% Reduction

2.4 GSI TBL Tool Overview

The GSI TBL tool includes a series of tabs within the Excel document, including key inputs, green stormwater infrastructure (GSI) scenario, costs timeline, and a range of co-benefits to explore. Inputs for this case study have been presented in the same order for ease of review.

2.4.1 Key Inputs

Key Inputs are summarized as Table 2-12.

Table 2-12. Fort Collins, CO – GSI TBL Tool Key Inputs.

Key Input	Unit	Unit of Measurement
Annual Rainfall that Results in Runoff	5.2	Inches
Design Storm Percentile	80	Percentile
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	0.6	Inches
Management Area	260	Acres
Management Area	0.406	Square Miles
Population Density	2,968	People/Square Mile
Management Area Population	1,206	People
Climate Zone	North	Unitless

2.4.2 GSI Scenario

Table 2-13 through Table 2-15 provide a summary of GSI practice drainage area and design specifications. The sand filter was modeled as a bioretention facility in the GSI TBL tool because it allowed for the closest comparison of data inputs.

Table 2-13. Fort Collins, CO – GSI TBL Tool Model Design Parameters – Permeable Pavement.

Design Parameter	Unit	Unit of Measurement
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	0.6	Inches
Storage Depth	8	Inches
Number of Practices (CLASIC) / Number of BMPs (GSI TBL Tool)	1	Unitless
Total Captured [Impervious] Area (CLASIC) / Effective Impervious Area Managed (GSI TBL Tool)	13.81	Acres
Total Technology Area (CLASIC) / Calculated BMP Area (GSI TBL Tool)	601,689	SF
Run-on-Ratio (Impervious Area Managed / BMP Area)	1.00	Unitless
Total Volume Captured (CLASIC) / Volume Capacity by BMP Type (GSI TBL Tool)	29,483	CF
Annual Runoff Volume	204,414	CF / Year
Annual Runoff Volume	4.69	Acre-Feet / Year
Annual Runoff Volume	1,529,015	Gallons / Year
Years to Replacement	35	Years

Table 2-14. Fort Collins, CO – GSI TBL Tool Model Design Parameters – Rain Garden.

Design Parameter	Unit	Unit of Measurement
Surface Area (CLASIC) / BMP Size (GSI TBL Tool)	1,000	SF
Ponding Depth	12	Inches
Filter Media Depth (CLASIC) / Depth (GSI TBL Tool)	18	Inches

Design Parameter	Unit	Unit of Measurement
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	0.6	Inches
Number of Practices (CLASIC) / Number of BMPs (GSI TBL Tool)	57	Unitless
Total Captured [Impervious] Area (CLASIC) / Effective Impervious Area Managed (GSI TBL Tool)	41.49	Acres
Total Technology Area (CLASIC) / Calculated BMP Area (GSI TBL Tool)	55,349	SF
Run-on-Ratio (Impervious Area Managed / BMP Area)	32.65	Unitless
Total Volume Captured (CLASIC) / Volume Capacity by BMP Type (GSI TBL Tool)	88,558	CF
Annual Runoff Volume	614,001	CF / Year
Annual Runoff Volume	14.10	Acre-Feet / Year
Annual Runoff Volume	4,592,731	Gallons / Year
Years to Replacement	25	Years

Table 2-15. Fort Collins, CO – GSI TBL Tool Model Design Parameters – Bioretention Facility (Sand Filter).

Design Parameter	Unit	Unit of Measurement
Surface Area (CLASIC) / BMP Size (GSI TBL Tool)	1,000	SF
Ponding Depth	12	Inches
Filter Media Depth (CLASIC) / Depth (GSI TBL Tool)	18	Inches
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	0.6	Inches

Design Parameter	Unit	Unit of Measurement
Number of Practices (CLASIC) / Number of BMPs (GSI TBL Tool)	38	Unitless
Total Captured [Impervious] Area (CLASIC) / Effective Impervious Area Managed (GSI TBL Tool)	27.32	Acres
Total Technology Area (CLASIC) / Calculated BMP Area (GSI TBL Tool)	55,349	SF
Run-on-Ratio (Impervious Area Managed / BMP Area)	32.7	Unitless
Total Volume Captured (CLASIC) / Volume Capacity by BMP Type (GSI TBL Tool)	58,313	CF
Annual Runoff Volume	404,303	CF / Year
Annual Runoff Volume	9.28	Acre-Feet / Year
Annual Runoff Volume	3,024,184	Gallons / Year
Years to Replacement	25	Years

2.4.3 Costs Timeline

Replacement costs are not automatically calculated for the GSI TBL Tool. For a more direct comparison, replacement costs and timelines were pulled from the CLASIC tool. Replacement costs were added at 25 years for the rain garden and bioretention facility (sand filter) and at 35 years for the permeable pavement.

2.4.4 Benefit Calculations

The GSI TBL Tool monetizes benefits across three benefit categories: financial, social, and environmental benefits. Each category is outlined in more detail below and net present values of the benefits are summarized in Table 2-18.

(1) Financial Benefit: Avoided Infrastructure Costs

The model for avoided cost associated with stormwater pumping and treatment was applied using the annual runoff volume retained in the GSI practices. The model assumes that 30% of this retained volume will result in avoided pumping and treatment.

(2) Financial Benefit: Avoided Replacement Costs

The model for avoided replacement costs for the use of permeable pavement was applied using the area of permeable pavement. The model assumes standard maintenance costs for traditional asphalt streets and parking lots, and that the permeable pavement will be used to replace 20% of an asphalt parking lot.

(3) Financial Benefit: Energy Savings

The volume of stormwater retained annually did not generate an energy savings benefit. Therefore, this benefit did not generate a credit.

(4) Social Benefit: Water Supply

The model for groundwater recharge benefit was applied using the annual runoff volume managed. The model assumes 50% infiltration to water supply aquifers and a 77.5% recharge efficiency rate.

(5) Social Benefit: Air Quality

The RMPA eGRID region and Rocky Mountains AVERT region were used to calculate energy savings from stormwater pumping and treatment. In addition, the model uses the area of vegetation from the rain garden and bioretention facility to calculate air pollutant removal benefits.

(6) Social Benefit: Property Values

Option 2 – Baseline Property Value was selected for this benefit calculation. Baseline counts and aggregate values of units by structure type were pulled from US Census data. The property value benefit was estimated based on the percentage of GSI practice area within the project study area. The model assumes that 20% of properties are excluded due to higher property values.

(7) Social Benefit: Heat Stress

The change in days where the city's temperature is above the minimum mortality temperature does not result in any reductions in heat-related deaths, emergency room visits, or hospitalizations. Therefore, the rain garden does not generate a heat stress credit.

(8) Social Benefit: Recreation

The project doesn't create any pocket parks, stormwater parks (e.g., parks that have stormwater management as a major component of the park upgrade) or wetland area recreation. However, the area does provide general neighborhood greening. It was determined that neighborhood greening occurs 4 months a year, and 100% of the management area that benefits from general neighborhood greening will support recreational activity.

(9) Social Benefit: Green Jobs

The avoided social cost valuation method was selected in this analysis.

(10) Environmental Benefit: Water Quality

The baseline water quality and expected water quality improvement values were not changed for the project. This project's water quality change does not occur in an estuary. The water quality change affects only local freshwater bodies that support recreation for 30% of the affected population. The median household income was calculated using the US Census and CPI inflation data. The number of households was calculated using the US Census and the ratio of the GSI management area to the total project city area.

(11) Environmental Benefit: Carbon

The carbon sequestration through rain gardens, bioretention, and wetlands model was used to calculate the carbon sequestration benefit. The NYCW eGRID region was selected to calculate energy savings. In addition, the tool uses the area of GSI practices to calculate carbon sequestered.

(12) Environmental Benefit: Improvements to Ecosystem Services

The tool uses the area of the GSI practices and the assumption that 80% of this area generates habitat creation. The area of the bioretention area was removed from this calculation since the sand filter is not expected to create habitat.

2.4.5 Results Dashboard

The net present value of the Fort Collins, Colorado project's total benefits accrued over the study period are valued at $6,328,634 while the net present value of the total costs accrued over the study period are estimated at $17,849,628. Dividing the lifetime benefits by the lifetime costs gives a benefit-cost ratio of 0.355. This means that for every $1 invested into the project, the project is expected to return $0.355 in realized benefits. Results are presented as Table 2-16 through Table 2-18.

Table 2-16. Fort Collins, CO – GSI TBL Tool Model Results: Stormwater Overview.

Stormwater GSI Practice	Volume Required (CF)	Volume Provided (CF)
Permeable Pavement	30,078	29,483
Rain Garden	90,365	88,558
Sand Filter	59,503	58,313
Total	**179,946**	**176,354**

Table 2-17. Fort Collins, CO – GSI TBL Tool Model Results: Lifecycle Costs.

Description	Present Value Cost (US Dollars)
Construction Cost	$ 7,210,634
Maintenance Cost	$ 5,989,420
Replacement Cost	$ 4,649,574
Total Lifecycle Cost	**$ 17,849,628**

Table 2-18. Fort Collins, CO – Overview of GSI TBL Tool Benefit Categories.

Benefit Category	Benefit Description	Net Present Value of Benefit
Financial	Avoided Infrastructure Costs	$ 121,961
Financial	Avoided Replacement Costs	$ 3,264,163
Financial	Energy Savings	$ -
Social	Water Supply	$ 465,973
Social	Air Quality	$ 42,080
Social	Increased Property Values	$ 222,113
Social	Heat Stress Reduction	$ -
Social	Recreation	$ 232,999
Social	Green Job Creation	$ 272,612
Environmental	Water Quality	$ 1,565,408
Environmental	Carbon Reduction	$ 71,415
Environmental	Improvements to Ecosystem Services	$ 69,910
Total Net Present Value of Benefits		**$ 6,328,634**

2.5 Comparison of Tools

A comparison of the volume, lifecycle costs, and co-benefits of the tools are shown in Table 2-19 through Table 2-21.

Table 2-19. Fort Collins, CO – Comparison of Stormwater Approach.

Description	Volume Provided (CF) CLASIC Tool	Volume Provided (CF) GSI TBL Tool
Permeable Pavement	160,450	29,483
Rain Garden	91,200	88,558
Sand Filter (CLASIC) / Bioretention (GSI TBL Tool)	60,800	58,313
Volume Provided	**312,450**	**176,354**

Table 2-20. Fort Collins, CO – Comparison of Lifecycle Costs.

Description	CLASIC Tool (US Dollars)	GSI TBL Tool (US Dollars)
Construction Cost	$ 9,829,008	$ 7,210,634
Maintenance Cost	$ 4,448,447	$ 5,989,420
Replacement Cost	$ 4,649,574	$ 4,649,574
Lifecycle Cost	**$ 18,927,029**	**$ 17,849,628**

Table 2-21. Fort Collins, CO – Comparison of Co-Benefits.

Description	CLASIC Tool (Out of 5 Each or 15 Total)		GSI TBL Tool (US Dollars)	
Social Benefits	4.00	42%	$ 1,235,777	20%
Financial Benefits	2.67	28%	$ 3,386,124	54%
Environmental Benefits	2.92	30%	$ 1,706,733	27%
Total Benefits	**9.59**	**100%**	**$ 6,328,634**	**100%**

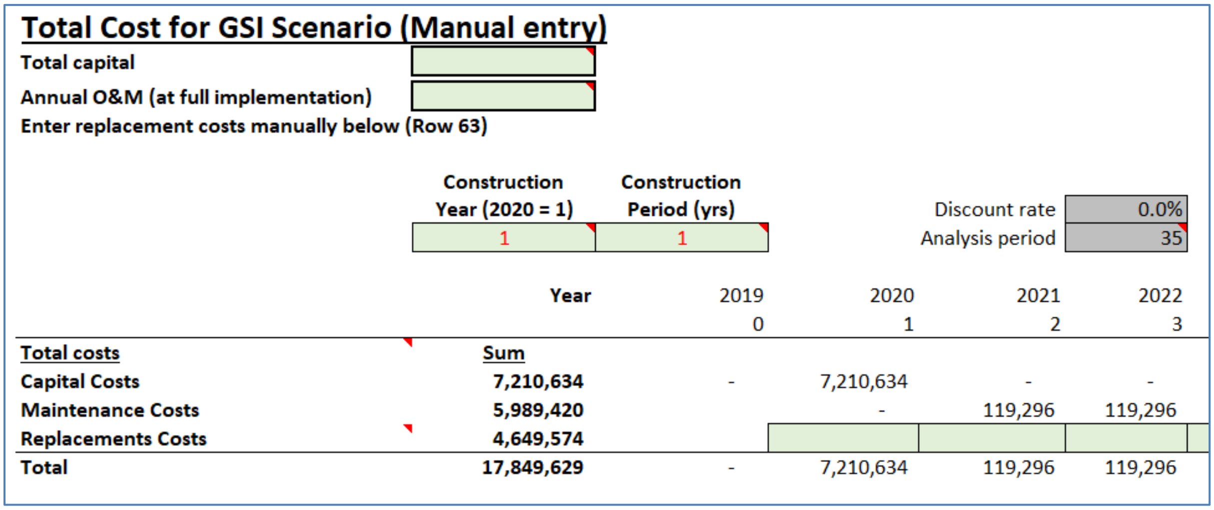
2.6 Key Takeaways

The following are key takeaways from the case study.

1. The tools do not use the same terminology as it relates to design storms, depths, GSI practices, and volumes.
2. Stormwater volume is calculated differently in the tools. In CLASIC, stormwater volume is based on the surface area of the GSI practice and the depth available to store water in the ponding and filter media layers. A void space of 40% is assigned to open graded aggregate/stone and soil storage layers. In the GSI TBL Tool, stormwater volume is based on design depth to capture (feet) and impervious drainage area (square feet), with a factor of 0.98 applied. The GSI TBL Tool consistently provided slightly lower volumes due to the 0.98 factor. The calculation for stormwater volume in permeable pavement systems accounted for the largest difference between the two tools. This is due to the minimum depth of stone required for pavement stability, which exceeded the design depth to capture in the case studies. In other words, permeable pavement systems can often handle a much larger storm event than the design depths attributed to GSI design.
3. The team experienced challenges with making modifications to the pre-populated design criteria in CLASIC. While the tool allowed for customizing the number of practices and drainage area, such modifications often caused the tool to malfunction. It was very challenging to customize the tool to fit the exact design parameters. For this reason, the team modified the design criteria to find a best fit within CLASIC.
4. The tools do not have the same GSI practices available. A sand filter is not one of the options in the GSI TBL tool so a bioretention area was utilized for this comparison. This may result in over-estimating of vegetation-related credits. The GSI TBL Tool user manual provides recommendations for removing vegetation benefits in the GSI Scenario tab. However, this created errors in calculating co-benefits value and therefore could not be used. While the GSI practice area that adds habitat could be adjusted for the Improvements to Ecosystem Services benefit, other credit categories were not as straight-forward to adjust.
5. Selecting the importance of co-benefits in the CLASIC tool requires the user to make assumptions based on their knowledge of the project. The CLASIC user manual could benefit from additional instructions, or future updates to the CLASIC tool could run the co-benefits analysis with more targeted user input based on project drivers, project location, or site-specific criteria.
6. Cost data in CLASIC is presented in both the “build scenarios” tab and within the final report. It appears that the costs presented in the build scenarios tab do not account for the number within each design category and/or the discounted cost over the full study period. The costs listed in the advanced tab appear to be per GSI practice, not per unit area or unit volume which is industry standard, and the basis of the GSI TBL Tool costing.
7. GSI practices that have class options (e.g., rain gardens, sand filters, infiltration trenches detention basin, and wet ponds) were found to range significantly in cost. For example, CLASIC notes that a small rain garden with a footprint of 100 square feet is approximately \$122/ square foot, whereas a large rain garden with a footprint of 10,000 square feet is approximately \$43/ square foot. This impact is an economy of scale effect.

8. The GSI TBL Tool required a much greater understanding of stormwater management design, benefits quantification, and economics than the CLASIC tool.
9. Both CLASIC and the GSI TBL tool account for vertical side slopes for rain garden and bioretention facilities, instead of sloped side slopes that are traditional for these types of GSI practices. As a result, system volumes and footprints may be underestimated.
10. For this case study, the pollutant load reductions in all categories are noted with a 64.2% reduction. The team was expecting to see a wider range of pollutant load reductions based on the specific GSI practice and pollutant parameter. Based on the CLASIC outputs provided to the user and without additional information provided in the manual, it was difficult to verify the calculations to understand why this was the case. The GSI TBL Tool does not provide outputs for pollutant load reductions.
11. The project boundary is not listed on the CLASIC output tab and seemed to disappear from the CLASIC data fields. As this parameter was needed for the GSI TBL Tool, it should be included in the CLASIC outputs.
12. There appear to be calculation errors in the GSI TBL Tool for the permeable pavement GSI practice. Adjustments to the construction period in the GSI TBL Tool caused a significant error in the construction cost for permeable pavement. See Figures 2-2 and Figure 2-3 for a permeable pavement practice screen shot from tool to demonstrate degree of error.

Figure 2-2. Fort Collins, CO – GSI TBL Tool Screenshot of Costs Timeline Screen (Construction Period 1 Year).



Total Cost for GSI Scenario (Manual entry)

Total capital

Annual O&M (at full implementation)

Enter replacement costs manually below (Row 63)

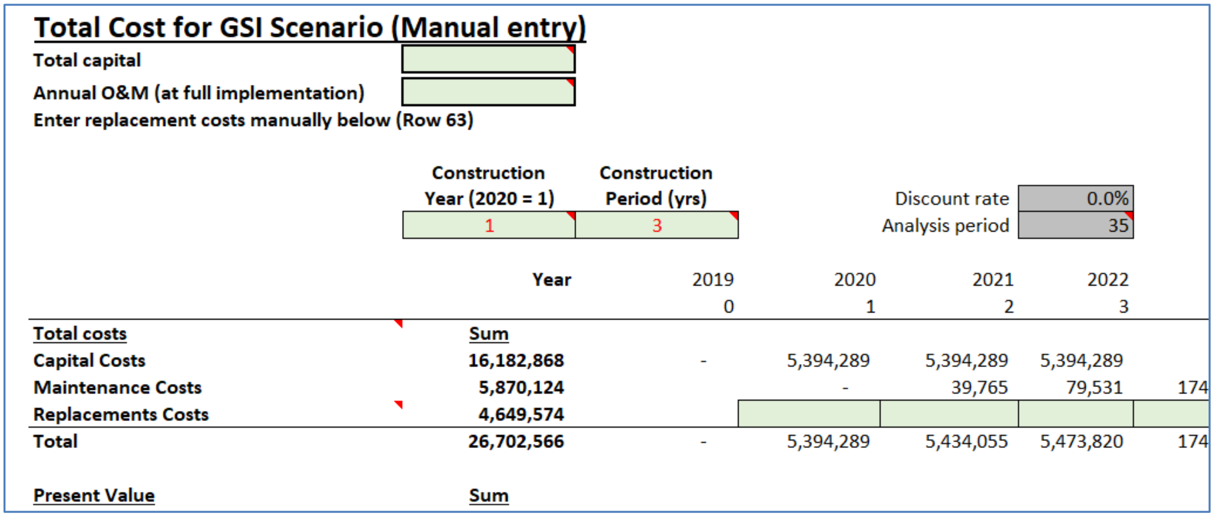
Construction Year (2020 = 1)	**Construction Period (yrs)**
1	1

Discount rate 0.0%

Analysis period 35

	Year	2019	2020	2021	2022
		0	1	2	3
Total costs	**Sum**				
Capital Costs	**7,210,634**	-	7,210,634	-	-
Maintenance Costs	**5,989,420**		-	119,296	119,296
Replacements Costs	**4,649,574**				
Total	**17,849,629**	-	7,210,634	119,296	119,296

Figure 2-3. Fort Collins, CO – GSI TBL Tool Screenshot of Costs Timeline Screen (Construction Period 3 Years).



Total Cost for GSI Scenario (Manual entry)

Total capital

Annual O&M (at full implementation)

Enter replacement costs manually below (Row 63)

Construction Year (2020 = 1): 1

Construction Period (yrs): 3

Discount rate: 0.0%

Analysis period: 35

	Year	2019	2020	2021	2022	
		0	1	2	3	
Total costs	**Sum**					
Capital Costs	**16,182,868**	-	5,394,289	5,394,289	5,394,289	
Maintenance Costs	**5,870,124**		-	39,765	79,531	174
Replacements Costs	**4,649,574**					
Total	**26,702,566**	-	5,394,289	5,434,055	5,473,820	174
Present Value	**Sum**					

13. The GSI TBL Tool does not calculate maintenance cost for permeable pavement correctly. The tool automatically splits the permeable pavement footprint listed in the GSI. Scenario tab evenly between the three pavement options (e.g., permeable pavement – concrete, permeable pavement – asphalt, and permeable pavement – pavers) on the Costs. Timelines tab (e.g., cells C77, C78, C79) but then only references the permeable pavement – concrete cell (e.g., cell C77) for the maintenance cost.
14. The team performed a sensitivity analysis to review the costs between the CLASIC and GSI TBL Tool. It was found that even if the unit prices were the same, the final construction cost did not match. Both tools could benefit from providing back-up for the cost estimates with options to override certain unit costs to provide more confidence in the results.
15. The permeable pavement practice in the GSI TBL Tool is reported with a significantly lower volume capacity than CLASIC.
16. It is unclear if there are any scalability concerns that the user should be aware of as it pertains to datasets used within CLASIC, specifically as it relates to subunits.

CHAPTER 3

Case Study #2: Philadelphia, Pennsylvania

3.1 Overview

This case study highlights a project in Philadelphia, Pennsylvania in the Northeast Climate Region. The key project driver is combined sewer overflow reduction. The case study includes the use of rain gardens and subsurface trenches to manage 16.70 acres of impervious cover.

3.2 Background

The City of Philadelphia is situated between the Schuylkill and Delaware Rivers within the Delaware River Basin. Philadelphia is one of America's earliest developed cities, with portions of the stormwater management system dating back more than 200 years. In the mid-19th century, it was common practice to discharge waste and trash into the waterways. To reduce exposure to pathogens, and to allow for development on the desired grid pattern, most of the natural stream beds were converted into closed, combined sewer systems. The combined sewer network makes up approximately 60 percent of the city's sewer system and is situated in the oldest and densest areas of the city. During rainfall events, the combined sewer system can become overwhelmed, often resulting in combined sewer overflows to the local waterways. "Green City, Clean Waters" is Philadelphia's long-term control plan to reduce combined sewer overflows with the use of distributed GSI in combination with targeted gray infrastructure upgrades. This case study highlights a hypothetical planning study using distributed GSI systems within the Lawncrest neighborhood to capture stormwater runoff to reduce combined sewer overflows.

Key model inputs included the items in Table 3-1. This case study was modeled from the Philadelphia Case Study – Scenario 2 on the CLASIC website. Where information was not clearly stated in the Case Study, assumptions were made and are noted below.

Table 3-1. Philadelphia, PA – Key Model Inputs. Philadelphia, PA – Key Model Inputs.

Feature	Value	Unit of Measurement
Average Annual Precipitation	40.4	Inches
Average Annual Runoff (CLASIC) or Annual Rainfall that Results in Runoff (GSI TBL Tool)	21.4	Inches
Cost Regionalization Factor	1.11	%
Annual Discount Factor (CLASIC) or Discount Rate (GSI TBL Tool)	3	%
Analysis Period	30	Years

An overview of the stormwater management approach is summarized in Table 3-2.

Table 3-2. Philadelphia, PA – Stormwater Overview.

Design Parameter	Rain Garden	Subsurface Infiltration Trench
Impervious Drainage Area (Acres)	8.35	8.35
Impervious Drainage Area (Square Feet)	363,726	363,726
Proposed BMP Footprint (Square Feet)	19,000	16,000
Proposed Surface Storage Depth (Feet) [100% Porosity]	1.00	0.00
Proposed Subsurface Storage Depth (Feet) [40% Porosity]	1.50	5.00
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool) (Feet)	0.08	0.08
Volume Required (CF)	30,311	30,311
Volume Provided (CF)	30,400	32,000

3.3 CLASIC Model Overview

CLASIC includes icons on the left side of the screen to guide the user through the steps of the CLASIC Tool. Inputs for this case study have been presented in the same order as the CLASIC guide for ease of review.

3.3.1 Define Study Area

A rectangular-shaped area was selected for the Lawncrest neighborhood using the draw on map function. This case study was run with a single subunit. Figure 3-1 illustrates the proposed project boundary.

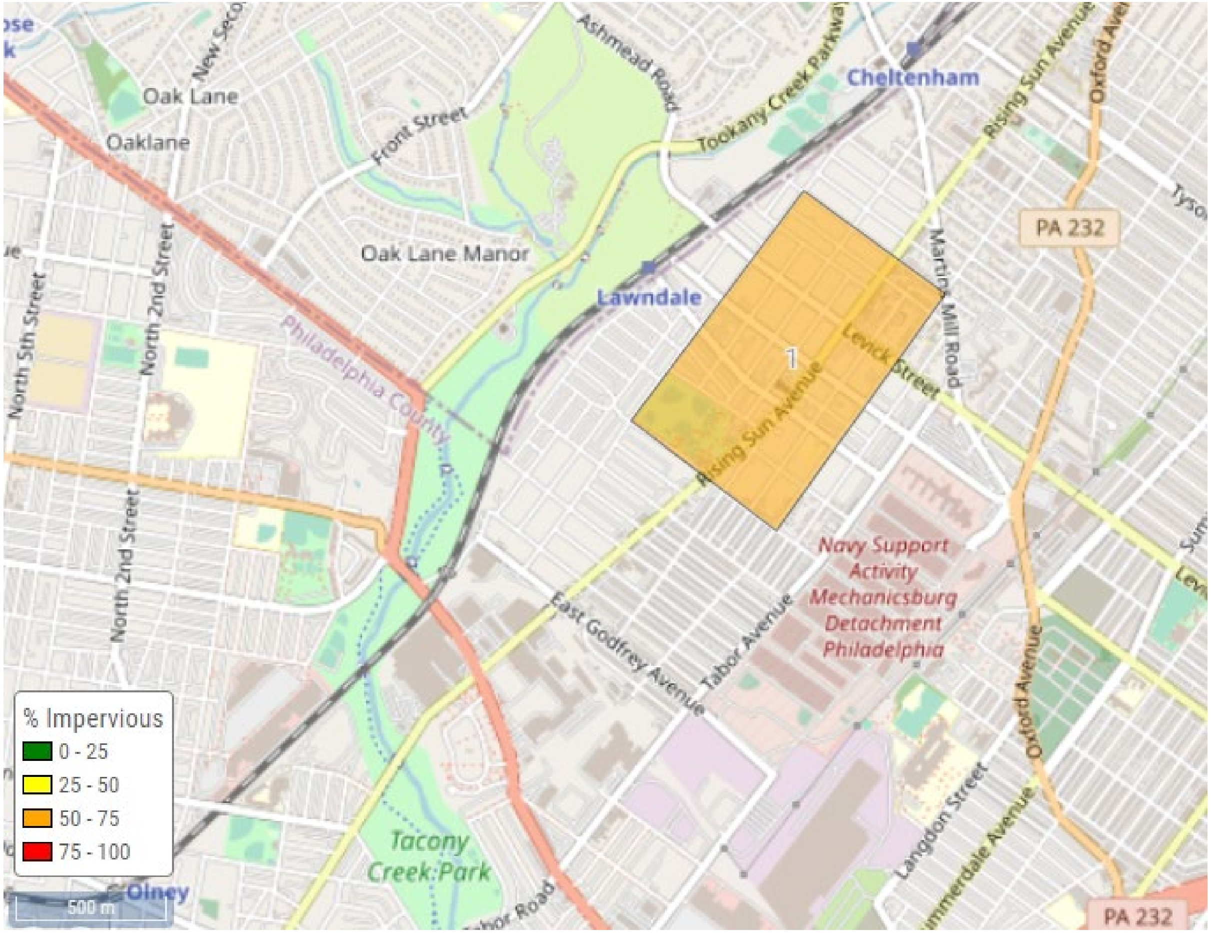
3.3.2 Select Climate Data

The Philadelphia International Airport precipitation station and the Northeast Philadelphia International Airport evaporation station were chosen.

3.3.3 Define Model Defaults

No modifications were made to the model default values.

Figure 3-1. Philadelphia, PA – Project Overview.



3.3.4 Build Scenarios

The rain garden and infiltration trench GSI practices were used for this case study. Design parameters are summarized in Table 3-3 and Table 3-4.

Table 3-3. Philadelphia, PA – CLASIC Model Design Parameters – Rain Garden.

Design Parameter	Unit	Unit of Measurement
Class	Medium	Unitless
Surface Area (CLASIC) / BMP Size (GSI TBL Tool)	1,000	SF
Ponding Depth	12	Inches
Filter Media Depth (CLASIC) / Depth (GSI TBL Tool)	18	Inches
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	1	Inches
Number of Practices (CLASIC) / Number of BMPs (GSI TBL Tool)	19	Unitless
Total Captured [Impervious] Area (CLASIC) / Effective Impervious Area Managed (GSI TBL Tool)	8.35	Acres
Total Technology Area (CLASIC) / Calculated BMP Area (GSI TBL Tool)	19,000	SF
Total Volume Captured (CLASIC) / Volume Capacity by BMP Type (GSI TBL Tool)	30,400	CF
Years to Replacement	25	Years

Table 3-4. Philadelphia, PA – CLASIC Model Design Parameters – Subsurface Infiltration Trench.

Design Parameter	Unit	Unit of Measurement
Class	Large	Unitless
Surface Area	2,000	SF
Ponding Depth	0	Inches
Filter Media Depth (CLASIC) / Depth (GSI TBL Tool)	60	Inches
Depth to Capture (CLASIC) / Design	1	Inches

Design Parameter	Unit	Unit of Measurement
Storm Depth (GSI TBL Tool)		
Number of Practices (CLASIC) / Calculated BMP Area (GSI TBL Tool)	8	Unitless
Total Captured [Impervious] Area (CLASIC) / Effective Impervious Area Managed (GSI TBL Tool)	8.35	Acres
Total Technology Area (CLASIC) / Calculated BMP Area (GSI TBL Tool)	16,000	SF
Total Volume Captured (CLASIC) / Volume Capacity by BMP Type (GSI TBL Tool)	32,000	CF
Years to Replacement	25	Years

3.3.5 Set Importance of Co-Benefits

Table 3-5 highlights the co-benefit factors that were identified as significant for this project. Inputs in this tab are used to develop the co-benefit analysis score. Please note that the assigned level of importance was developed by the research team based on their understanding of the project and tool inputs.

Table 3-5. Philadelphia, PA – CLASIC Model Co-Benefit Analysis Importance Factors.

Co-Benefit Category	Co-Benefit	CLASIC Parameter Used for Estimation	Assigned Level of Importance
Financial	Increased Property Values	Reduction in Impervious Cover / Increase in Green Space	Very Important
Financial	Reduced Costs from Illness	Increase in Plants, Trees, and Green Roofs	Somewhat Important
Financial	Avoided Costs from Combined Sewer Treatment	Combined Sewer Systems Only; Runoff Volume Reduction	Very Important
Financial	Reduced or Mitigated Impacts from Nuisance Floods	Runoff Volume Reduction	Very Important

Co-Benefit Category	Co-Benefit	CLASIC Parameter Used for Estimation	Assigned Level of Importance
Financial	Enhanced Building Energy Efficiency	Area of Green Roof	Not Important
Financial	Avoided Water Treatment	Volume of Stormwater Harvested	Not Important
Financial	Improvements to Employment Opportunities	Annual Maintenance Cost	Very Important
Social	Health Benefits from Improvements to Air Quality	Increase in Plants, Trees, and Green Roofs	Somewhat Important
Social	Mental Health Improvements	Reduction in Impervious Cover / Increase in Green Space	Somewhat Important
Social	Improvements to Thermal Health	Reduction in Impervious Cover / Increase in Green Space	Somewhat Important
Social	Increased Supply from Harvested Stormwater	Volume of Stormwater Harvested	Not Important
Social	Increased Public Awareness of Stormwater and Water Systems	Number of Stormwater GSI practices	Very Important
Social	Potential Avoided Social Strain Associated with Nuisance Flooding	Runoff Volume Reduction	Very Important
Environmental	Improvements to Ecosystem Services	Diversity of Vegetation	Very Important
Environmental	Increased Groundwater Flow	Runoff Volume Infiltrated	Somewhat Important
Environmental	Carbon Sequestration	Increase in Plants, Trees, and Green Roofs	Somewhat Important

3.3.6 Set Targets

Targets were not included in the case study.

3.3.7 Results

A baseline scenario was not developed for this case study. Therefore, results will be compared to a "do nothing" scenario. Results are presented as Table 3-6 through Table 3-10.

Table 3-6. Philadelphia, PA – CLASIC Model Results: Stormwater Overview.

Stormwater GSI Practice	Volume Required (CF)	Volume Provided (CF)
Rain Garden	30,311	30,400
Subsurface Infiltration Trench	30,311	32,000
Total	**60,621**	**62,400**

Table 3-7. Philadelphia, PA – CLASIC Model Results: Lifecycle Cost.

Description	Present Value Cost (US Dollars)
Construction Cost	$ 1,745,284
Maintenance Cost	$ 774,666
Replacement Cost	$ 499,106
Total Lifecycle Cost	**$ 3,019,056**

Table 3-8. Philadelphia, PA – CLASIC Model Results: Co-Benefits.

Description	Co-Benefit Score (Out of 5 Each or 15 Total)
Social Benefits Score	4.00
Economic Score	3.50
Environmental Score	4.17
Total Score	**11.67**

Table 3-9. Philadelphia, PA – CLASIC Model Results: Hydrologic Performance.

Description	Percentage Change from Baseline
Average Annual Runoff (Inches)	11.1% Reduction
Average Annual Infiltration (Inches)	14.0% Increase
Average Annual Evaporation (Inches)	3.2% Increase

Table 3-10. Philadelphia, PA – CLASIC Model Results: Water Quality Performance.

Description	Percentage Change from Baseline
Total Suspended Solids	17.1% Reduction
Total Nitrogen	15.2% Reduction
Total Phosphorus	15.7% Reduction
Fecal Indicator Bacteria	17.6% Reduction

3.4 GSI TBL Tool Overview

The GSI TBL tool includes a series of tabs within the Excel document, including key inputs, green stormwater infrastructure (GSI) scenario, costs timeline, and a range of co-benefits to explore. Inputs for this case study have been presented in the same order for ease of review.

3.4.1 Key Inputs

Key Inputs are summarized as Table 3-11.

Table 3-11. Philadelphia, PA – GSI TBL Tool Key Inputs.

Key Input	Unit	Unit of Measurement
Annual Rainfall that Results in Runoff	21.4	Inches
Design Storm Percentile	85	Percentile
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	1	Inches
Management Area	141	Acres
Management Area	0.220	Square Miles
Population Density	12,465	People/Square Mile

Key Input	Unit	Unit of Measurement
Management Area Population	2,746	People
Climate Zone	Northeast	Unitless

3.4.2 GSI Scenario

Table 3-12 and Table 3-13 provide a summary of GSI practice drainage area and design specifications. The infiltration trench was modeled as a bioretention facility in the GSI TBL tool because it allowed for the closest comparison of data inputs.

Table 3-12. Philadelphia, PA – GSI TBL Tool Model Design Parameters – Rain Garden.

Design Parameter	Unit	Unit of Measurement
Surface Area (CLASIC) / BMP Size (GSI TBL Tool)	1,000	SF
Ponding Depth	12	Inches
Filter Media Depth (CLASIC) / Depth (GSI TBL Tool)	18	Inches
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	1	Inches
Number of Practices (CLASIC) / Number of BMPs (GSI TBL Tool)	19	Unitless
Total Captured [Impervious] Area (CLASIC) / Effective Impervious Area Managed (GSI TBL Tool)	8.35	Acres
Total Technology Area (CLASIC) / Calculated BMP Area (GSI TBL Tool)	18,565	SF
Run-on-Ratio (Impervious Area Managed / BMP Area)	19.6	Unitless
Total Volume Captured (CLASIC) / Volume Capacity by BMP Type (GSI TBL Tool)	29,704	CF
Annual Runoff Volume	540,321	CF / Year
Annual Runoff Volume	12.40	Acre-Feet / Year

Design Parameter	Unit	Unit of Measurement
Annual Runoff Volume	4,041,601	Gallons / Year
Years to Replacement	25	Years

Table 3-13. Philadelphia, PA – GSI TBL Tool Model Design Parameters – Bioretention Facility (Subsurface Infiltration Trench).

Design Parameter	Unit	Unit of Measurement
Surface Area (CLASIC) / BMP Size (GSI TBL Tool)	2,000	SF
Ponding Depth	0	Inches
Filter Media Depth (CLASIC) / Depth (GSI TBL Tool)	60	Inches
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	1	Inches
Number of Practices (CLASIC) / Number of BMPs (GSI TBL Tool)	7	Unitless
Total Captured [Impervious] Area (CLASIC) / Effective Impervious Area Managed (GSI TBL Tool)	8.35	Acres
Total Technology Area (CLASIC) / Calculated BMP Area (GSI TBL Tool)	14,852	SF
Run-on-Ratio (Impervious Area Managed / BMP Area)	24.5	Unitless
Total Volume Captured (CLASIC) / Volume Capacity by BMP Type (GSI TBL Tool)	29,704	CF
Annual Runoff Volume	540,321	CF / Year
Annual Runoff Volume	12.40	Acre-Feet / Year
Annual Runoff Volume	4,041,601	Gallons / Year

Design Parameter	Unit	Unit of Measurement
Years to Replacement	25	Years

3.4.3 Costs Timeline

Replacement costs are not automatically calculated for the GSI TBL Tool. For a more direct comparison, replacement costs and timelines were pulled from the CLASIC tool. Replacement costs were added at 25 years for the rain garden and bioretention facility (infiltration trench).

3.4.4 Benefit Calculations

The GSI TBL Tool monetizes benefits across three benefit categories: financial, social, and environmental benefits. Each category is outlined in more detail below and net present values of the benefits are summarized in Table 3-16.

(1) Financial Benefit: Avoided Infrastructure Costs
The model for avoided cost associated with stormwater pumping and treatment was applied using the annual runoff volume retained in the GSI practices. The model assumes that 30% of this retained volume will result in avoided pumping and treatment.

(2) Financial Benefit: Avoided Replacement Costs
This benefit does not apply since the project does not include green roofs or permeable pavement.

(3) Financial Benefit: Energy Savings
The volume of stormwater retained annually did not generate an energy savings benefit. Therefore, this benefit did not generate a credit.

(4) Social Benefit: Water Supply
The model for groundwater recharge benefit was applied using the annual runoff volume managed. The model assumes 50% infiltration to water supply aquifers and a 77.5% recharge efficiency rate.

(5) Social Benefit: Air Quality
The NYCW eGRID region and Great Lakes / Mid-Atlantic AVERT region were used to calculate energy savings from stormwater pumping and treatment. In addition, the model uses the area of vegetation from the rain garden and bioretention facility to calculate air pollutant removal benefits.

(6) Social Benefit: Property Values
Option 2 – Baseline Property Value was selected for this benefit calculation. Baseline counts and aggregate values of units by structure type were pulled from US Census data. The property value benefit was estimated based on the percentage of GSI practice area within the project study area. The model assumes that 10% of properties are excluded due to higher property values.

(7) Social Benefit: Heat Stress

Although the addition of permeable pavement covers 5% of the management area, the change in days where the city's temperature is above the minimum mortality temperature does not result in any reductions in heat-related deaths, emergency room visits, or hospitalizations. Therefore, the porous pavement does not generate a heat stress credit.

(8) Social Benefit: Recreation

The project doesn't create any pocket parks, stormwater parks (e.g., parks that have stormwater management as a major component of the park upgrade), or wetland area recreation. However, the area does provide general neighborhood greening. It was determined that neighborhood greening occurs 4 months a year, and 100% of the management area that benefits from general neighborhood greening will support recreational activity.

(9) Social Benefit: Green Jobs

The avoided social cost valuation method was selected in this analysis.

(10) Environmental Benefit: Water Quality

The baseline water quality and expected water quality improvement values were not changed for the project. This project's water quality change does not occur in an estuary. The water quality change affects only local freshwater bodies that support recreation for 30% of the affected population. The median household income was calculated using the US Census and CPI inflation data. The number of households was calculated using the US Census and the ratio of the GSI management area to the total project city area.

(11) Environmental Benefit: Carbon

The carbon sequestration through rain gardens, bioretention, and wetlands model was used to calculate the carbon sequestration benefit. The RMPA eGRID region was selected to calculate energy savings. In addition, the tool uses the area of GSI practices to calculate carbon sequestered.

(12) Environmental Benefit: Improvements to Ecosystem Services

The tool uses the area of the GSI practices and the assumption that 80% of this area generates habitat creation.

3.4.5 Results Dashboard

The net present value of the Philadelphia, Pennsylvania project's total benefits accrued over the study period are valued at $2,320,877 while the net present value of the total costs accrued over the study period are estimated at $2,033,352. Dividing the lifetime benefits by the lifetime costs gives a benefit-cost ratio of 1.141. This means that for every $1 invested into the project, the project is expected to return $1.141 in realized benefits. Results are presented as Table 3-14 through Table 3-16.

Table 3-14. Philadelphia, PA – GSI TBL Tool Model Results: Volume.

Stormwater GSI Practice	Volume Required (CF)	Volume Provided (CF)
Rain Garden	30,311	29,704
Bioretention Facility (Subsurface Infiltration Trench)	30,311	29,704
Total	**60,621**	**59,409**

Table 3-15. Philadelphia, PA – GSI TBL Tool Model Results: Lifecycle Costs.

Description	Present Value Cost (US Dollars)
Construction Cost	$ 916,940
Maintenance Cost	$ 617,306
Replacement Cost	$ 499,106
Total Lifecycle Cost	**$ 2,033,352**

Table 3-16. Philadelphia, PA – GSI TBL Tool Model Results: Co-Benefits.

Benefit Category	Benefit Description	Net Present Value of Benefit
Financial	Avoided Infrastructure Costs	$ 58,605
Financial	Avoided Replacement Costs	$ -
Financial	Energy Savings	$ -
Social	Water Supply	$ 223,912
Social	Air Quality	$ 35,333
Social	Increased Property Values	$ 98,724
Social	Heat Stress Reduction	$ -
Social	Recreation	$ 288,448
Social	Green Job Creation	$ 31,934
Environmental	Water Quality	$ 1,550,630

Benefit Category	Benefit Description	Net Present Value of Benefit
Environmental	Carbon	$ 20,542
Environmental	Improvements to Ecosystem Services	$ 12,749
Total Net Present Value of Benefits		**$ 2,320,877**

3.5 Comparison of Tools

A comparison of the volume, lifecycle costs, and co-benefits of the tools are shown in Table 3-17 through Table 3-19.

Table 3-17. Philadelphia, PA – Comparison of Stormwater Approach.

Description	Volume Provided (CF) CLASIC Tool	Volume Provided (CF) GSI TBL Tool
Rain Garden	30,400	29,704
Underground Infiltration Basin (CLASIC) / Bioretention (GSI TBL Tool)	32,000	29,704
Volume Provided	**62,400**	**59,409**

Table 3-18. Philadelphia, PA – Comparison of Lifecycle Costs.

Description	CLASIC Tool (US Dollars)	GSI TBL Tool (US Dollars)
Construction Cost	$ 1,745,284	$ 916,940
Maintenance Cost	$ 774,666	$ 617,306
Replacement Cost	$ 499,106	$ 499,106
Lifecycle Cost	**$ 3,019,056**	**$ 2,033,352**

Table 3-19. Philadelphia, PA – Comparison of Co-Benefits.

Description	CLASIC Tool (Out of 5 Each or 15 Total)		GSI TBL Tool (US Dollars)	
Social Benefits	4.00	34%	$ 678,351	29%
Financial Benefits	3.50	30%	$ 58,605	3%
Environmental Benefits	4.17	36%	$ 1,583,921	68%
Total Benefits	**11.67**	**100%**	**$ 2,320,877**	**100%**

3.6 Key Takeaways

The following are key takeaways from the case study.

1. The tools do not use the same terminology as it relates to design storms, depths, GSI practices, and volumes.
2. Stormwater volume is calculated differently in the tools. In CLASIC, stormwater volume is based on the surface area of the GSI practice and the depth available to store water in the ponding and filter media layers. A void space of 40% is assigned to open graded aggregate/stone and soil storage layers. In the GSI TBL Tool, stormwater volume is based on design depth to capture (feet) and impervious drainage area (square feet), with a factor of 0.98 applied. The GSI TBL Tool consistently provided slightly lower volumes due to the 0.98 factor.
3. The team experienced challenges with making modifications to the pre-populated design criteria in CLASIC. While the tool allowed for customizing the number of GSI practices and drainage area, such modifications often caused the tool to malfunction. It was very challenging to customize the tool to fit the exact design parameters. For this reason, the team modified the design criteria to find a best fit within CLASIC.
4. The tools do not have the same GSI practices available. An underground infiltration basin is not one of the options in the GSI TBL tool so a bioretention area was utilized for this comparison.
5. Selecting the importance of co-benefits in the CLASIC tool requires the user to make assumptions based on their knowledge of the project. The CLASIC user manual could benefit from additional instructions, or future updates to the CLASIC tool could run the co-benefits analysis with more targeted user input based on project drivers, project location, or site-specific criteria.
6. Cost data in CLASIC is presented in both the “build scenarios” tab and within the final report. It appears that the costs presented in the build scenarios tab do not account for the number within each design category and/or the discounted cost over the full study period. The costs listed in the advanced tab appear to be per GSI practice, not per unit area or unit volume which is industry standard, and the basis of the GSI TBL Tool costing.

7. GSI practices that have class options (e.g., rain gardens, sand filters, infiltration trenches detention basin, and wet ponds) were found to range significantly in cost. For example, CLASIC notes that a small rain garden with a footprint of 100 square feet is approximately $122/ square foot, whereas a large rain garden with a footprint of 10,000 square feet is approximately $43/ square foot. This impact is an economy of scale effect.
8. The GSI TBL Tool required a much greater understanding of stormwater management design, benefits quantification, and economics than the CLASIC tool.
9. Both CLASIC and the GSI TBL tool account for vertical side slopes for rain garden and bioretention facilities, instead of sloped side slopes that are traditional for these types of GSI practices. As a result, system volumes and footprints may be underestimated.
10. The project boundary is not listed on the CLASIC output tab and seemed to disappear from the CLASIC data fields. As this parameter was needed for the GSI TBL Tool, it should be included in the CLASIC outputs.
11. CLASIC includes a regional cost factor based on proximity to major cities. It is unclear if the GSI TBL Tool includes such a factor.
12. Page 86 of GSI TBL Tool user manual indicates vegetated benefits of a given GSI practice can be removed from the co-benefits calculation by entering 0 for the footprint in the GSI.Scenarios tab. However, when this was done for the bioretention practice as a test, errors were generated, and a benefits cost was unable to be calculated.

CHAPTER 4

Case Study #3: New Orleans, Louisiana

4.1 Overview

This case study highlights a project in New Orleans, Louisiana in the South Climate Region. The key project drivers are flood risk and subsidence reduction. The case study includes the use of rain gardens and wet ponds to manage 287.61 acres of impervious cover.

4.2 Background

New Orleans is a coastal city in Louisiana within the Mississippi River delta. The city has three distinct waterfronts including Lake Pontchartrain to the north, the Mississippi River to the south and west, and coastal wetlands along the Gulf of Mexico to the east. The city is surrounded by water on all sides, with much of the city at or below sea level. In the most extreme cases, neighborhoods sit up to 8 feet below sea level. This topography creates a “bowl-shaped” community susceptible to flooding.

The city is surrounded by perimeter controls, such as levees and floodwalls, to provide storm surge protection to keep water out of the city. The drainage system operates under a pumped drainage model where every drop of water that lands within the “bowl” is pumped to Lake Pontchartrain. New Orleans receives approximately 68 inches of rainfall annually, resulting in frequent pumping of stormwater. The pump stations are often overwhelmed by small rainfall events since the pump capacity cannot keep up with the peaks in rainfall intensity, resulting in street flooding. Although pumping reduces the risk of flooding within the city, this pumping has increased the rate of soil subsidence.

To reduce the burden on existing pump stations and to encourage groundwater recharge, the city has adopted a “living with water” approach where nature-based solutions are prioritized for the interior drainage system. This case study explores the use of linear wetlands and rain gardens to provide much-needed storage to reduce flooding. This case study highlights components from the Blue and Green Corridors Project, one of the projects outlined in the Gentilly Resilience District Plan. Key model inputs included the items in Table 4-1.

Table 4-1. New Orleans, LA – Key Model Inputs.

Feature	Value	Unit of Measurement
Average Annual Precipitation	68	Inches
Average Annual Runoff (CLASIC) or Annual Rainfall that Results in Runoff (GSI TBL Tool)	25.5	Inches
Cost Regionalization Factor	1	%
Annual Discount Factor (CLASIC) or Discount Rate (GSI TBL Tool)	3	%
Analysis Period	30	Years

An overview of the stormwater management approach is summarized in Table 4-2.

Table 4-2. New Orleans, LA – Stormwater Overview.

Design Parameter	Rain Garden	Wet Pond
Impervious Drainage Area (Acres)	3.63	283.98
Impervious Drainage Area (Square Feet)	158,123	12,370,169
Proposed BMP Footprint (Square Feet)	12,000	3,172,000
Proposed Surface Storage Depth (Feet) [100% Porosity]	0.50	4.00
Proposed Subsurface Storage Depth (Feet) [40% Porosity]	1.50	0.00
Permanent Pool Depth (Feet) [0% Porosity]	0.00	5.00
Permanent Pool Surface Area (Square Feet)	0.00	2,028,000.00
Top of Pond Surface Area (Square Feet)	0.00	3,172,000.00
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool) (Feet)	0.08	0.83
Volume Required (CF)	13,177	10,308,474
Volume Provided (CF)	13,200	10,400,000

4.3 CLASIC Model Overview

CLASIC includes icons on the left side of the screen to guide the user through the steps of the CLASIC Tool. Inputs for this case study have been presented in the same order as the CLASIC guide for ease of review.

4.3.1 Define Study Area

The polygon tool was used to draw the drainage boundary for the project. This case study was run with a single subunit. Figure 4-1 illustrates the proposed project boundary.

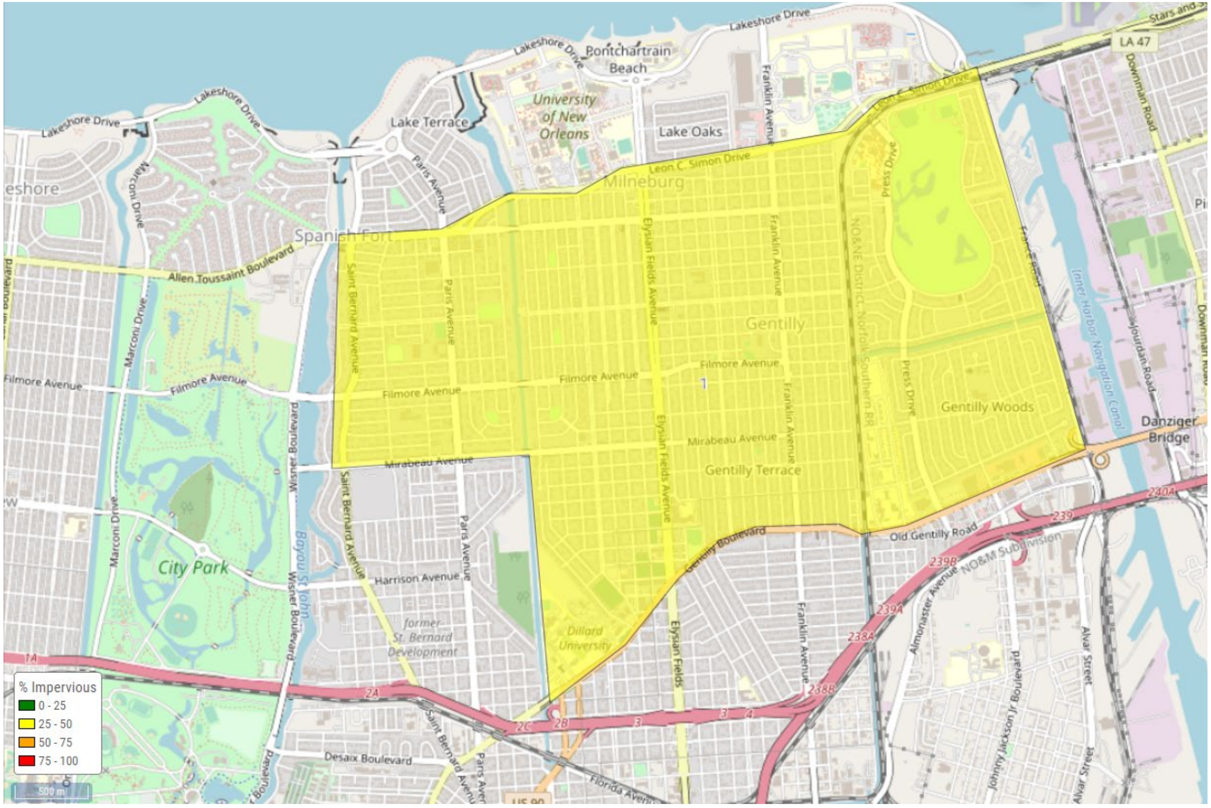
4.3.2 Select Climate Data

The New Orleans Audubon precipitation and evaporation stations were chosen.

4.3.3 Define Model Defaults

No modifications were made to the model default values.

Figure 4-1. New Orleans, LA – Project Overview.



4.3.4 Build Scenarios

The rain garden and wet pond practices were used for this case study. Design parameters are summarized in Table 4-3 and Table 4-4.

Table 4-3. New Orleans, LA – CLASIC Model Design Parameters – Rain Garden.

Design Parameter	Unit	Unit of Measurement
Class	Small	Unitless
Surface Area (CLASIC) / BMP Size (GSI TBL Tool)	100	SF
Ponding Depth	6	Inches
Filter Media Depth (CLASIC) / Depth (GSI TBL Tool)	18	Inches
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	1	Inches
Number of Practices (CLASIC) / Number of BMPs (GSI TBL Tool)	120	Unitless
Total Captured [Impervious] Area (CLASIC) / Effective Impervious Area Managed (GSI TBL Tool)	3.63	Acres
Total Technology Area (CLASIC) / Calculated BMP Area (GSI TBL Tool)	12,000	SF
Total Volume Captured (CLASIC) / Volume Capacity by BMP Type (GSI TBL Tool)	13,200	CF
Years to Replacement	25	Years

Table 4-4. New Orleans, LA – CLASIC Model Design Parameters – Wet Pond.

Design Parameter	Unit	Unit of Measurement
Class	Medium	Unitless
Basin Volume	100,000	CF
Top Surface Area (CLASIC) / BMP Size (GSI TBL Tool)	30,500	SF
Permanent Pool Surface Area	19,500[1]	SF
Basin Depth (CLASIC) / Ponding Depth (GSI TBL Tool)	48	Inches
Permanent Pool Depth	60	Inches
Permanent Pool Volume	91,000	CF
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	10	Inches
Number of Practices (CLASIC) / Calculated BMP Area (GSI TBL Tool)	104	Unitless
Total Captured [Impervious] Area (CLASIC) / Effective Impervious Area Managed (GSI TBL Tool)	283.98	Acres
Total Technology Area (CLASIC) / Calculated BMP Area (GSI TBL Tool)	3,172,000	SF
Total Volume Captured (CLASIC) / Volume Capacity by BMP Type (GSI TBL Tool)	10,400,000	CF
Years to Replacement	35	Years

[1] The surface area of the permanent pool has been adjusted from 20,000 SF to 19,500 SF to properly account for the volume noted in CLASIC of 100,000 CF. This calculation assumes a prismatic shape and constant side slopes.

4.3.5 Set Importance of Co-Benefits

Table 4-5 highlights the co-benefit factors that were identified as significant for this project. Inputs in this tab are used to develop the co-benefit analysis score. Please note that the assigned level of importance was developed by the research team based on their understanding of the project and tool inputs.

Table 4-5. New Orleans, LA – CLASIC Model Co-Benefit Analysis Importance Factors.

Co-Benefit Category	Co-Benefit	CLASIC Parameter Used for Estimation	Assigned Level of Importance
Financial	Increased Property Values	Reduction in Impervious Cover / Increase in Green Space	Very Important
Financial	Reduced Costs from Illness	Increase in Plants, Trees, and Green Roofs	Medium Importance
Financial	Avoided Costs from Combined Sewer Treatment	Combined Sewer Systems Only; Runoff Volume Reduction	Not Important
Financial	Reduced or Mitigated Impacts from Nuisance Floods	Runoff Volume Reduction	Very Important
Financial	Enhanced Building Energy Efficiency	Area of Green Roof	Not Important
Financial	Avoided Water Treatment	Volume of Stormwater Harvested	Not Important
Financial	Improvements to Employment Opportunities	Annual Maintenance Cost	Very Important
Social	Health Benefits from Improvements to Air Quality	Increase in Plants, Trees, and Green Roofs	Medium Importance
Social	Mental Health Improvements	Reduction in Impervious Cover / Increase in Green Space	Medium Importance
Social	Improvements to	Reduction in Impervious Cover / Increase in Green	Medium

Co-Benefit Category	Co-Benefit	CLASIC Parameter Used for Estimation	Assigned Level of Importance
	Thermal Health	Space	Importance
Social	Increased Supply from Harvested Stormwater	Volume of Stormwater Harvested	Not Important
Social	Increased Public Awareness of Stormwater and Water Systems	Number of Stormwater Practices	Very Important
Social	Potential Avoided Social Strain Associated with Nuisance Flooding	Runoff Volume Reduction	Very Important
Environmental	Improvements to Ecosystem Services	Diversity of Vegetation	Very Important
Environmental	Increased Groundwater Flow	Runoff Volume Infiltrated	Somewhat Important
Environmental	Carbon Sequestration	Increase in Plants, Trees, and Green Roofs	Medium Importance

4.3.6 Set Targets

Targets were not included in the case study.

4.3.7 Results

A baseline scenario was not developed for this case study. Therefore, results will be compared to a "do nothing" scenario. Results are presented as Table 4-6 through Table 4-10.

Table 4-6. New Orleans, LA – CLASIC Model Results: Stormwater Overview.

Stormwater GSI Practice	Volume Required (CF)	Volume Provided (CF)
Rain Garden	13,177	13,200
Wet Pond	10,308,474	10,400,000
Total	**10,321,651**	**10,413,200**

Table 4-7. New Orleans, LA – CLASIC Model Results: Lifecycle Cost.

Description	Present Value Cost (US Dollars)
Construction Cost	$ 12,263,144
Maintenance Cost	$ 15,185,361
Replacement Cost	$ 430,246
Total Lifecycle Cost	**$ 27,878,751**

Table 4-8. New Orleans, LA – CLASIC Model Results: Co-Benefits.

Description	Co-Benefit Score (Out of 5 Each or 15 Total)
Social Benefits Score	3.00
Economic Score	2.50
Environmental Score	0.96
Total Score	**6.46**

Table 4-9. New Orleans, LA – CLASIC Model Results: Hydrologic Performance.

Description	Percentage Change from Baseline
Average Annual Runoff (Inches)	5.6% Increase[1]
Average Annual Infiltration (Inches)	3.9% Decrease[1]
Average Annual Evaporation (Inches)	5.5% Increase

[1] The results of the hydrologic performance in this table are not what was expected, as the results show an increase in annual runoff and a decrease in annual infiltration. The opposite was expected given the large storage volume provided with the wet pond and the addition of infiltration-based practices via the rain gardens. The team acknowledges that there appears to be an issue with the model but obtained same results when model was rerun.

Table 4-10. New Orleans, LA – CLASIC Model Results: Water Quality Performance.

Description	Percentage Change from Baseline
Total Suspended Solids	17.8% Reduction
Total Nitrogen	7.5% Reduction
Total Phosphorus	11.4% Reduction
Fecal Indicator Bacteria	16.7% Reduction

4.4 GSI TBL Tool Overview

The GSI TBL tool includes a series of tabs within the Excel document, including key inputs, green stormwater infrastructure (GSI) scenario, costs timeline, and a range of co-benefits to explore. Inputs for this case study have been presented in the same order for ease of review.

4.4.1 Key Inputs

Key Inputs are summarized as Table 4-11.

Table 4-11. New Orleans, LA – GSI TBL Tool Key Inputs.

Key Input	Unit	Unit of Measurement
Annual Rainfall that Results in Runoff	25.5	Inches
Design Storm Percentile	85	Percentile
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	1	Inches
Management Area	2,989	Acres
Management Area	4.670	Square Miles
Population Density	2,260	People/Square Mile
Management Area Population	10,555	People
Climate Zone	Coastal Plain	Unitless

4.4.2 GSI Scenario

Table 4-12 and Table 4-13 provide a summary of GSI practice drainage area and design specifications. The sand filter was modeled as a bioretention facility in the GSI TBL tool because it allowed for the closest comparison of data inputs. In the GSI TBL Tool, the depth to capture is provided on the key inputs tab, and generally meant for the storm event that produces 1-2 inches of runoff, or the water quality volume. The volume capacity by BMP type cell was adjusted in the GSI TBL Tool to account for the full capture of 10 inches of runoff, to match inputs to CLASIC.

Table 4-12. New Orleans, LA – GSI TBL Tool Model Design Parameters – Rain Garden.

Design Parameter	Unit	Unit of Measurement
Surface Area (CLASIC) / BMP Size (GSI TBL Tool)	100	SF
Ponding Depth	6	Inches
Filter Media Depth (CLASIC) / Depth (GSI TBL Tool)	18	Inches
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	1	Inches
Number of Practices (CLASIC) / Number of BMPs (GSI TBL Tool)	117	Unitless
Total Captured [Impervious] Area (CLASIC) / Effective Impervious Area Managed (GSI TBL Tool)	3.63	Acres
Total Technology Area (CLASIC) / Calculated BMP Area (GSI TBL Tool)	11,739	SF
Run-on-Ratio (Impervious Area Managed / BMP Area)	13.5	Unitless
Total Volume Captured (CLASIC) / Volume Capacity by BMP Type (GSI TBL Tool)	12,913	CF
Annual Runoff Volume	279,897	CF / Year
Annual Runoff Volume	6.43	Acre-Feet / Year
Annual Runoff Volume	2,093,633	Gallons / Year
Years to Replacement	25	Years

Table 4-13. New Orleans, LA – GSI TBL Tool Model Design Parameters – Wet Pond.

Design Parameter	Unit	Unit of Measurement
Surface Area (CLASIC) / BMP Size (GSI TBL Tool)	30,500	SF
Ponding Depth	48	Inches
Filter Media Depth (CLASIC) / Depth (GSI TBL Tool)	0	Inches
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	10	Inches
Number of Practices (CLASIC) / Number of BMPs (GSI TBL Tool)	83	Unitless
Total Captured [Impervious] Area (CLASIC) / Effective Impervious Area Managed (GSI TBL Tool)	283.98	Acres
Total Technology Area (CLASIC) / Calculated BMP Area (GSI TBL Tool)	2,525,576	SF
Run-on-Ratio (Impervious Area Managed / BMP Area)	49.0	Unitless
Total Volume Captured (CLASIC) / Volume Capacity by BMP Type (GSI TBL Tool)	10,102,305	CF
Annual Runoff Volume	21,896,745	CF / Year
Annual Runoff Volume	502.68	Acre-Feet / Year
Annual Runoff Volume	163,787,656	Gallons / Year
Years to Replacement	35	Years

4.4.3 Costs Timeline

Replacement costs are not automatically calculated for the GSI TBL Tool. For a more direct comparison, replacement costs and timelines were pulled from the CLASIC tool. Replacement costs were added at 25 years for the rain garden and bioretention facility (sand filter) and at 35 years for the permeable pavement.

4.4.4 Benefit Calculations

The GSI TBL Tool monetizes benefits across three benefit categories: financial, social, and environmental benefits. Each category is outlined in more detail below and net present values of the benefits are summarized in Table 4-15.

(1) Financial Benefit: Avoided Infrastructure Costs

The model for avoided cost associated with stormwater pumping and treatment was applied using the annual runoff volume retained in the GSI practices. The model assumes that 30% of this retained volume will result in avoided pumping and treatment.

(2) Financial Benefit: Avoided Replacement Costs

The model for avoided replacement costs for the use of permeable pavement was applied using the area of permeable pavement. The model assumes standard maintenance costs for traditional asphalt streets and parking lots, and that the permeable pavement will be used to replace 20% of an asphalt parking lot.

(3) Financial Benefit: Energy Savings

The volume of stormwater retained annually did not generate an energy savings benefit. Therefore, this benefit did not generate a credit.

(4) Social Benefit: Water Supply

The model for groundwater recharge benefit was applied using the annual runoff volume managed. The model assumes 50% infiltration to water supply aquifers and a 77.5% recharge efficiency rate.

(5) Social Benefit: Air Quality

The RMPA eGRID region and Rocky Mountains AVERT region were used to calculate energy savings from stormwater pumping and treatment. In addition, the model uses the area of vegetation from the rain garden and bioretention facility to calculate air pollutant removal benefits.

(6) Social Benefit: Property Values

Option 2 – Baseline Property Value was selected for this benefit calculation. Baseline counts and aggregate values of units by structure type were pulled from US Census data. The property value benefit was estimated based on the percentage of GSI practice area within the project study area. The model assumes that 20% of properties are excluded due to higher property values.

(7) Social Benefit: Heat Stress

Although the addition of permeable pavement covers 5% of the management area, the change in days where the city’s temperature is above the minimum mortality temperature does not result in any reductions in heat-related deaths, emergency room visits, or hospitalizations. Therefore, the porous pavement does not generate a heat stress credit.

(8) Social Benefit: Recreation

The project doesn't create any pocket parks, stormwater parks (e.g., parks that have stormwater management as a major component of the park upgrade), or wetland area recreation. However, the area does provide general neighborhood greening. It was determined that neighborhood greening occurs 4 months a year, and 100% of the management area that benefits from general neighborhood greening will support recreational activity.

(9) Social Benefit: Green Jobs

The avoided social cost valuation method was selected in this analysis.

(10) Environmental Benefit: Water Quality

The baseline water quality and expected water quality improvement values were not changed for the project. This project's water quality change does not occur in an estuary. The water quality change affects only local freshwater bodies that support recreation for 30% of the affected population. The median household income was calculated using the US Census and CPI inflation data. The number of households was calculated using the US Census and the ratio of the GSI management area to the total project city area.

(11) Environmental Benefit: Carbon

The carbon sequestration through rain gardens, bioretention, and wetlands model was used to calculate the carbon sequestration benefit. The RMPA eGRID region was selected to calculate energy savings. In addition, the tool uses the area of GSI practices to calculate carbon sequestered.

(12) Environmental Benefit: Improvements to Ecosystem Services

The tool uses the area of the GSI practices and the assumption that 80% of this area generates habitat creation.

4.4.5 Results Dashboard

The net present value of the New Orleans, Louisiana project's total benefits accrued over the study period are valued at $6,373,464 while the net present value of the total costs accrued over the study period are estimated at $17,849,628. Dividing the lifetime benefits by the lifetime costs gives a benefit-cost ratio of 0.357. This means that for every $1 invested into the project, the project is expected to return $0.357 in realized benefits. Results are presented as Table 4-14 through Table 4-16.

Table 4-14. New Orleans, LA – GSI TBL Tool Model Results: Volume.

Stormwater GSI Practice	Volume Required (CF)	Volume Provided (CF)
Rain Garden	13,177	12,913
Wet Pond	10,308,474	10,102,305
Total	**10,321,651**	**10,115,218**

Table 4-15. New Orleans, LA – GSI TBL Tool Model Results: Lifecycle Costs.

Description	Present Value Cost (US Dollars)
Construction Cost	$ 2,116,531
Maintenance Cost	$ 6,074,637
Replacement Cost	$ 430,246
Total Lifecycle Cost	**$ 8,621,414**

Table 4-16. New Orleans, LA – GSI TBL Tool Model Results: Co-Benefits.

Benefit Category	Benefit Description	Net Present Value of Benefit
Financial	Avoided Infrastructure Costs	$ 21,107,362
Financial	Avoided Replacement Costs	$ -
Financial	Energy Savings	$ -
Social	Water Supply	$ -
Social	Air Quality	$ 834,497
Social	Increased Property Values	$ 859,326
Social	Heat Stress Reduction	$ -
Social	Recreation	$ 3,326,191
Social	Green Job Creation	$ 80,921
Environmental	Water Quality	$ 5,818,328

Benefit Category	Benefit Description	Net Present Value of Benefit
Environmental	Carbon	$ 367,772
Environmental	Improvements to Ecosystem Services	$ 2,609,424
Total Net Present Value of Benefits		**$ 35,003,821**

4.5 Comparison of Tools

A comparison of the volume, lifecycle costs, and co-benefits of the tools are shown in Table 4-17 through Table 4-19.

Table 4-17. New Orleans, LA – Comparison of Stormwater Approach.

Description	Volume Provided (CF) CLASIC Tool	Volume Provided (CF) GSI TBL Tool
Rain Garden	13,200	12,913
Wet Pond	10,400,000	10,102,305
Volume Provided	**10,413,200**	**10,115,218**

Table 4-18. New Orleans, LA – Comparison of Lifecycle Costs.

Description	CLASIC Tool (US Dollars)	GSI TBL Tool (US Dollars)
Construction Cost	$ 12,263,144	$ 2,116,531
Maintenance Cost	$ 15,185,361	$ 6,074,637
Replacement Cost	$ 430,246	$ 430,246
Lifecycle Cost	**$ 27,878,751**	**$ 8,621,414**

Table 4-19. New Orleans, LA – Comparison of Co-Benefits.

Description	CLASIC Tool (Out of 5 Each or 15 Total)		GSI TBL Tool (US Dollars)	
Social Benefits	4.00	34%	$ 678,351	29%
Financial Benefits	3.50	30%	$ 58,605	3%

Environmental Benefits	4.17	36%	$ 1,571,172	68%
Total Benefits	**11.67**	**100%**	**$ 2,308,128**	**100%**

4.6 Key Takeaways

The following are key takeaways from the case study.

1. The tools do not use the same terminology as it relates to design storms, depths, practices, and volumes.
2. Stormwater volume is calculated differently in the tools. In CLASIC, stormwater volume is based on the surface area of the GSI practice and the depth available to store water in the ponding and filter media layers. A void space of 40% is assigned to open graded aggregate/stone and soil storage layers. In the GSI TBL Tool, stormwater volume is based on design depth to capture (feet) and impervious drainage area (square feet), with a factor of 0.98 applied. The GSI TBL Tool consistently provided slightly lower volumes due to the 0.98 factor.
3. The team experienced challenges with making modifications to the pre-populated design criteria in CLASIC. While the tool allowed for customizing the number of practices and drainage area, such modifications often caused the tool to malfunction. It was very challenging to customize the tool to fit the exact design parameters. For this reason, the team modified the design criteria to find a best fit within CLASIC.
4. Selecting the importance of co-benefits in the CLASIC tool requires the user to make assumptions based on their knowledge of the project. The CLASIC user manual could benefit from additional instructions, or future updates to the CLASIC tool could run the co-benefits analysis with more targeted user input based on project drivers, project location, or site-specific criteria.
5. Cost data in CLASIC is presented in both the “build scenarios” tab and within the final report. It appears that the costs presented in the build scenarios tab do not account for the number within each design category and/or the discounted cost over the full study period. The costs listed in the advanced tab appear to be per GSI practice, not per unit area or unit volume which is industry standard, and the basis of the GSI TBL Tool costing.
6. Practices that have class options (e.g., rain gardens, sand filters, infiltration trenches detention basin, and wet ponds) were found to range significantly in cost. For example, CLASIC notes that a small rain garden with a footprint of 100 square feet is approximately $122/ square foot, whereas a large rain garden with a footprint of 10,000 square feet is approximately $43/ square foot. This impact is an economy of scale effect.
7. The GSI TBL Tool required a much greater understanding of stormwater management design, benefits quantification, and economics than the CLASIC tool.
8. Both CLASIC and the GSI TBL tool account for vertical side slopes for rain garden and bioretention facilities, instead of sloped side slopes that is traditional for these types of practices. As a result, system volumes and footprints may be underestimated.

9. Based on the CLASIC outputs provided to the user and without additional information or calculations provided in the manual, it was difficult to verify the percent reduction in runoff and pollutant loads. The GSI TBL Tool does not provide outputs for pollutant load reductions.
10. The project boundary is not listed on the CLASIC output tab and seemed to disappear from the CLASIC data fields. As this parameter was needed for the GSI TBL Tool, it should be included in the CLASIC outputs.
11. The stormwater management features for this case study were designed for two different design storm depths. The rain gardens were designed to manage a 1-inch storm event, while the wet pond was designed to manage a 10-inch storm event. CLASIC allows for modifications to the design storm within the GSI practice drop-down menus. However, the design storm is entered once on the Key.Inputs tab within the GSI TBL Tool. The project team adjusted the volume capacity by BMP type cell (e.g., cell H34) to manually adjust the design storm for the wet pond.
12. The GSI TBL Tool appears to have several calculation errors tied to the wet pond practice. The project team found that if the project only includes a wet pond, the co-benefits tool does not generate a value and returns an error on the Results.Dashboard tab.
13. The unit cost for the wet pond is noted as $0.67/cubic foot on the Costs.Timeline tab (e.g., cell C41). However, the footprint area for the wet pond appears to be used in the actual cost calculations below (e.g., cell C80). In addition, it is unclear if the wet pond calculation accounts for the extra excavation for the permanent pool. CLASIC assumed a permanent pool depth of 5 feet.
14. The results of the hydrologic performance in CLASIC are not what was expected, as the results show an increase in annual runoff and a decrease in annual infiltration. The opposite was expected given the large storage volume provided with the wet pond and the addition of infiltration-based practices.

CHAPTER 5

Case Study #4: Phoenix, Arizona

5.1 Overview

This case study highlights a project in Phoenix, Arizona in the Southwest Climate Region. The key project drivers are water conservation and urban heat island reduction. The case study includes the use of rain gardens and permeable pavement to manage 2.23 acres of impervious cover.

5.2 Background

Phoenix is the fifth largest city in the United States, encompassing an area of approximately 600 square miles. The city is in a dry, desert environment, characterized by only 7 inches of rain per year, high evaporation rates, and low soil permeability. On average, there are 15 distinct rainfall events annually with a measured rainfall of over 0.10 inches, about four of these which provide rainfall greater than 0.5 inches. The city recognizes the value of GSI in addressing stormwater management and other City priorities such as conserving water supply and open space, reducing the urban heat index, creating heat protection for more bikeable and walkable streets, as well as improving air quality.

The city has several specific characteristics which affect the merits of GSI – rainwater harvesting, green roofs, barrels, and cisterns pose less practicality than in other jurisdictions. Historically, much of the rainfall has fallen during the winter season, when many plants are dormant or have minimal water needs. May and June are the hottest and driest months of the year, with almost no rainfall. During the summer wet season (July-October), stone monsoon storms generate highly localized, short-lived, intense storm events that fall within a very specific area. One short rain event can exceed the design storm for a GSI feature, while a mile away, a GSI feature may have received no rain or water at all. Storing collected rainwater for extended periods for future use can present challenges from evaporation and vector control. There are many dry washes and ephemeral washes but few intermittent or perennial streams or rivers in the region. This case study explores the use of porous pavement and bioswales to promote water conservation and reduce the urban heat index. Figure 5-1 provides an overview of the project.

Design details were used to provide a comparison of the WRF CLASIC and GSI TBL tool outputs only and should not be relied upon for anything outside the scope of this research project. Key model inputs included the items in Table 5-1.

Table 5-1. Phoenix, AZ – Key Model Inputs.

Feature	Value	Unit of Measurement
Average Annual Precipitation	7.3	Inches
Average Annual Runoff (CLASIC) or Annual Rainfall that Results in Runoff (GSI TBL Tool)	3.8	Inches
Cost Regionalization Factor	0.88	%
Annual Discount Factor (CLASIC) or Discount Rate (GSI TBL Tool)	3	%
Analysis Period	30	Years

An overview of the stormwater management approach is summarized in Table 5-2.

Table 5-2. Phoenix, AZ – Stormwater Overview.

Design Parameter	Permeable Pavement	Rain Garden
Impervious Drainage Area (Acres)	1.89	0.34
Impervious Drainage Area (Square Feet)	82,289	14,810
Proposed BMP Footprint (Square Feet)	82,289	1,200
Proposed Surface Storage Depth (Feet) [100% Porosity]	0.00	0.50
Proposed Subsurface Storage Depth (Feet) [40% Porosity]	0.67	1.50
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool) (Feet)	0.08	0.08
Volume Required (CF)	6,857	1,234
Volume Provided (CF)	21,944	1,320

5.3 CLASIC Model Overview

CLASIC includes icons on the left side of the screen to guide the user through the steps of the CLASIC Tool. Inputs for this case study have been presented in the same order as the CLASIC guide for ease of review.

5.3.1 Define Study Area

A rectangular-shaped area was selected for the project location using the draw on map function. This case study was run with a single subunit. Figure 5-1 illustrates the proposed project boundary.

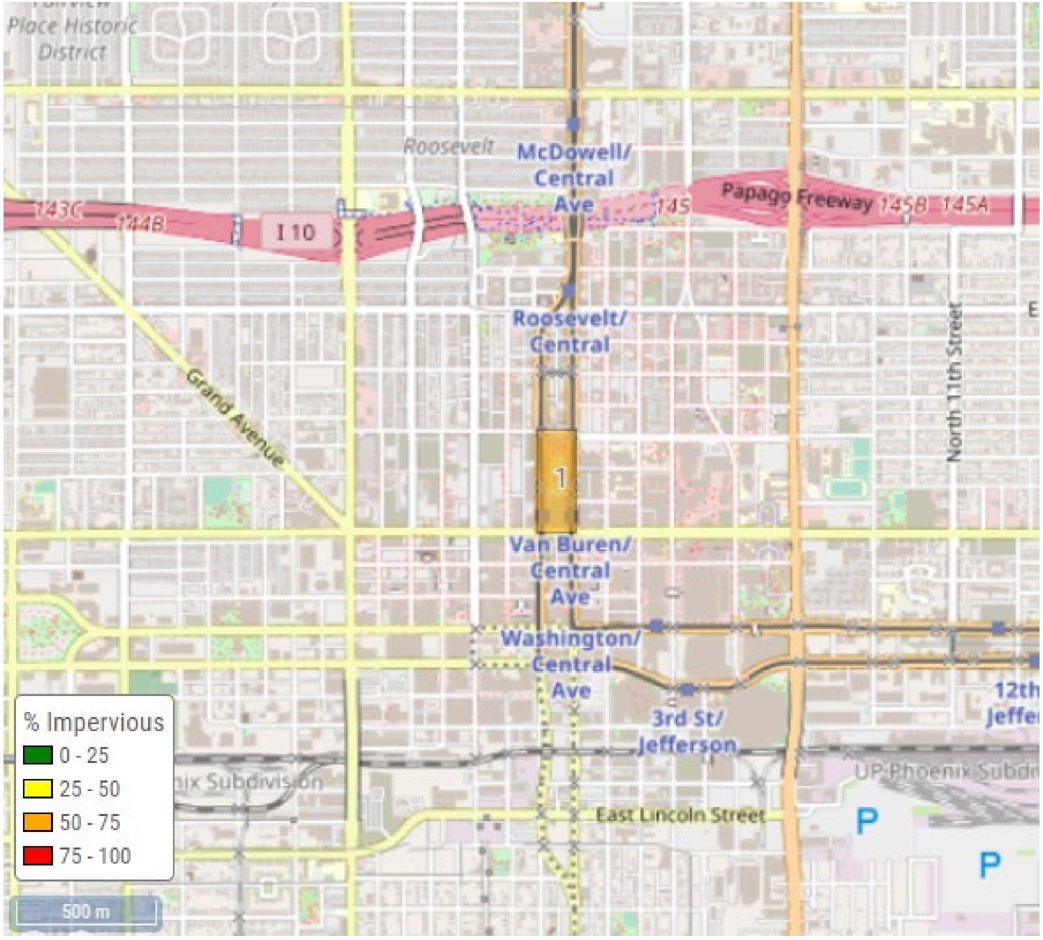
5.3.2 Select Climate Data

The Phoenix Airport precipitation and evaporation stations were chosen.

5.3.3 Define Model Defaults

No modifications were made to the model default values.

Figure 5-1. Phoenix, AZ – Project Overview.



5.3.4 Build Scenarios

The rain garden and permeable pavement practices were used for this case study. Design parameters are summarized in Table 5-3 and Table 5-4.

Table 5-3. Phoenix, AZ – CLASIC Model Design Parameters – Permeable Pavement.

Design Parameter	Unit	Unit of Measurement
Pavement Material	Pavers	Unitless
Run-on-Ratio	0:01	Unitless
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	1	Inches
Storage Depth	8.00	Inches
Number of Practices (CLASIC) / Number of BMPs (GSI TBL Tool)	1	Unitless
Total Captured [Impervious] Area (CLASIC) / Effective Impervious Area Managed (GSI TBL Tool)	1.89	Acres
Total Technology Area (CLASIC) / Calculated BMP Area (GSI TBL Tool)	82,289	SF
Total Volume Captured (CLASIC) / Volume Capacity by BMP Type (GSI TBL Tool)	21,944	CF
Years to Replacement	35	Years

Table 5-4. Phoenix, AZ – CLASIC Model Design Parameters –Rain Garden.

Design Parameter	Unit	Unit of Measurement
Class	Small	Unitless
Surface Area (CLASIC) / BMP Size (GSI TBL Tool)	100	SF
Ponding Depth	6	Inches
Filter Media Depth (CLASIC) / Depth (GSI TBL Tool)	18	Inches
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	1	Inches

Design Parameter	Unit	Unit of Measurement
Number of Practices (CLASIC) / Number of BMPs (GSI TBL Tool)	12	Unitless
Total Captured [Impervious] Area (CLASIC) / Effective Impervious Area Managed (GSI TBL Tool)	0.34	Acres
Total Technology Area (CLASIC) / Calculated BMP Area (GSI TBL Tool)	1,200	SF
Total Volume Captured (CLASIC) / Volume Capacity by BMP Type (GSI TBL Tool)	1,320	CF
Years to Replacement	25	Years

5.3.5 Set Importance of Co-Benefits

Table 5-5 highlights the co-benefit factors that were identified as significant for this project. Inputs in this tab are used to develop the co-benefit analysis score. Please note that the assigned level of importance was developed by the research team based on their understanding of the project and tool inputs.

Table 5-5. Phoenix, AZ – CLASIC Model Co-Benefit Analysis Importance Factors.

Co-Benefit Category	Co-Benefit	CLASIC Parameter Used for Estimation	Assigned Level of Importance
Financial	Increased Property Values	Reduction in Impervious Cover / Increase in Green Space	Medium Importance
Financial	Reduced Costs from Illness	Increase in Plants, Trees, and Green Roofs	Medium Importance
Financial	Avoided Costs from Combined Sewer Treatment	Combined Sewer Systems Only; Runoff Volume Reduction	N/A
Financial	Reduced or Mitigated Impacts from Nuisance Floods	Runoff Volume Reduction	Very Important
Financial	Enhanced Building	Area of Green Roof	N/A

Co-Benefit Category	**Co-Benefit**	**CLASIC Parameter Used for Estimation**	**Assigned Level of Importance**
	Energy Efficiency		
Financial	Avoided Water Treatment	Volume of Stormwater Harvested	N/A
Financial	Improvements to Employment Opportunities	Annual Maintenance Cost	Very Important
Social	Health Benefits from Improvements to Air Quality	Increase in Plants, Trees, and Green Roofs	Medium Importance
Social	Mental Health Improvements	Reduction in Impervious Cover / Increase in Green Space	Medium Importance
Social	Improvements to Thermal Health	Reduction in Impervious Cover / Increase in Green Space	Medium Importance
Social	Increased Supply from Harvested Stormwater	Volume of Stormwater Harvested	N/A
Social	Increased Public Awareness of Stormwater and Water Systems	Number of Stormwater Practices	Very Important
Social	Potential Avoided Social Strain Associated with Nuisance Flooding	Runoff Volume Reduction	Very Important
Environmental	Improvements to Ecosystem Services	Diversity of Vegetation	Medium Importance
Environmental	Increased Groundwater Flow	Runoff Volume Infiltrated	Somewhat Important

Co-Benefit Category	Co-Benefit	CLASIC Parameter Used for Estimation	Assigned Level of Importance
Environmental	Carbon Sequestration	Increase in Plants, Trees, and Green Roofs	Medium Importance

5.3.6 Set Targets

Targets were not included in the case study.

5.3.7 Results

A baseline scenario was not developed for this case study. Therefore, results will be compared to a “do nothing” scenario. Results are presented as Table 5-6 through Table 5-10.

Table 5-6. Phoenix, AZ – CLASIC Model Results: Volume.

Stormwater GSI Practice	Volume Required (CF)	Volume Provided (CF)
Permeable Pavement	6,857	21,944
Rain Garden	1,234	1,320
Total	**8,092**	**23,264**

Table 5-7. Phoenix, AZ– CLASIC Model Results: Lifecycle Cost.

Description	Present Value Cost (US Dollars)
Construction Cost	$ 833,610
Maintenance Cost	$ 169,875
Replacement Cost	$ 47,197
Total Lifecycle Cost	**$ 1,050,682**

Table 5-8. Phoenix, AZ – CLASIC Model Results: Co-Benefits.

Description	Co-Benefit Score (Out of 5 Each or 15 Total)
Social Benefits Score	4.72
Economic Score	3.83
Environmental Score	4.29

Description	Co-Benefit Score (Out of 5 Each or 15 Total)
Total Score	**12.84**

Table 5-9. Phoenix, AZ – CLASIC Model Results: Hydrologic Performance.

Description	Percentage Change from Baseline
Average Annual Runoff (Inches)	29% Decrease
Average Annual Infiltration (Inches)	45.8% Increase
Average Annual Evaporation (Inches)	18.2% Decrease

Table 5-10. Phoenix, AZ – CLASIC Model Results: Water Quality Performance.

Description	Percentage Change from Baseline
Total Suspended Solids	29% Reduction
Total Nitrogen	29% Reduction
Total Phosphorus	29% Reduction
Fecal Indicator Bacteria	29% Reduction

5.4 GSI TBL Tool Overview

The GSI TBL tool includes a series of tabs within the Excel document, including key inputs, green stormwater infrastructure (GSI) scenario, costs timeline, and a range of co-benefits to explore. Inputs for this case study have been presented in the same order for ease of review.

5.4.1 Key Inputs

Key Inputs are summarized as Table 5-11.

Table 5-11. Phoenix, AZ – GSI TBL Tool Key Inputs.

Key Input	Unit	Unit of Measurement
Annual Rainfall that Results in Runoff	5.2	Inches
Design Storm Percentile	80	Percentile
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	0.6	Inches
Management Area	260	Acres

Management Area	0.406	Square Miles
Population Density	2,968	People/Square Mile
Management Area Population	1,206	People
Climate Zone	Southwest	Unitless

5.4.2 GSI Scenario

Table 5-12 and Table 5-13 provide a summary of GSI practice drainage area and design specifications. The sand filter was modeled as a bioretention facility in the GSI TBL tool because it allowed for the closest comparison of data inputs.

Table 5-12. Phoenix, AZ – GSI TBL Tool Model Design Parameters – Permeable Pavement.

Design Parameter	Unit	Unit of Measurement
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	1	Inches
Storage Depth	8.0	Inches
Number of Practices (CLASIC) / Number of BMPs (GSI TBL Tool)	1	Unitless
Total Captured [Impervious] Area (CLASIC) / Effective Impervious Area Managed (GSI TBL Tool)	1.89	Acres
Total Technology Area (CLASIC) / Calculated BMP Area (GSI TBL Tool)	82,289	SF
Run-on-Ratio (Impervious Area Managed / BMP Area)	1.00	Unitless
Total Volume Captured (CLASIC) / Volume Capacity by BMP Type (GSI TBL Tool)	6,720	CF
Annual Runoff Volume	21,706	CF / Year
Annual Runoff Volume	0.50	Acre-Feet / Year
Annual Runoff Volume	162,364	Gallons / Year

Design Parameter	Unit	Unit of Measurement
Years to Replacement	35	Years

Table 5-13. Phoenix, AZ – GSI TBL Tool Model Design Parameters – Rain Garden.

Design Parameter	Unit	Unit of Measurement
Surface Area (CLASIC) / BMP Size (GSI TBL Tool)	100	SF
Ponding Depth	6	Inches
Filter Media Depth (CLASIC) / Depth (GSI TBL Tool)	18	Inches
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	1	Inches
Number of Practices (CLASIC) / Number of BMPs (GSI TBL Tool)	11	Unitless
Total Captured [Impervious] Area (CLASIC) / Effective Impervious Area Managed (GSI TBL Tool)	0.34	Acres
Total Technology Area (CLASIC) / Calculated BMP Area (GSI TBL Tool)	1,100	SF
Run-on-Ratio (Impervious Area Managed / BMP Area)	13.47	Unitless
Total Volume Captured (CLASIC) / Volume Capacity by BMP Type (GSI TBL Tool)	1,209	CF
Annual Runoff Volume	3,907	CF / Year
Annual Runoff Volume	0.09	Acre-Feet / Year
Annual Runoff Volume	29,222	Gallons / Year
Years to Replacement	25	Years

5.4.3 Costs Timeline

Replacement costs are not automatically calculated for the GSI TBL Tool. For a more direct comparison, replacement costs and timelines were pulled from the CLASIC tool. Replacement costs were added at 25 years for the rain garden and at 35 years for the permeable pavement.

5.4.4 Benefit Calculations

The GSI TBL Tool monetizes benefits across three benefit categories: financial, social, and environmental benefits. Each category is outlined in more detail below and net present values of the benefits are summarized in Table 5-16.

(1) Financial Benefit: Avoided Infrastructure Costs

The model for avoided cost associated with stormwater pumping and treatment was applied using the annual runoff volume retained in the GSI practices. The model assumes that 30% of this retained volume will result in avoided pumping and treatment.

(2) Financial Benefit: Avoided Replacement Costs

The model for avoided replacement costs for the use of permeable pavement was applied using the area of permeable pavement. The model assumes standard maintenance costs for traditional asphalt streets and parking lots, and that the permeable pavement will be used to replace 20% of an asphalt parking lot.

(3) Financial Benefit: Energy Savings

The volume of stormwater retained annually did not generate an energy savings benefit. Therefore, this benefit did not generate a credit.

(4) Social Benefit: Water Supply

The model for groundwater recharge benefit was applied using the annual runoff volume managed. The model assumes 50% infiltration to water supply aquifers and a 77.5% recharge efficiency rate.

(5) Social Benefit: Air Quality

The AZNM eGRID region and Southwest AVERT region were used to calculate energy savings from stormwater pumping and treatment. In addition, the model uses the area of vegetation from the rain garden and bioretention facility to calculate air pollutant removal benefits.

(6) Social Benefit: Property Values

Option 2 – Baseline Property Value was selected for this benefit calculation. Baseline counts and aggregate values of units by structure type were pulled from US Census data. The property value benefit was estimated based on the percentage of GSI practice area within the project study area. The model assumes that 20% of properties are excluded due to higher property values.

(7) Social Benefit: Heat Stress

The change in days where the city’s temperature is above the minimum mortality temperature does not result in any reductions in heat-related deaths, emergency room visits, or hospitalizations. Therefore, the rain garden does not generate a heat stress credit.

(8) Social Benefit: Recreation

The project provides general neighborhood greening. It was determined that neighborhood greening occurs 7 months a year, and 100% of the management area that benefits from general neighborhood greening will support recreational activity.

(9) Social Benefit: Green Jobs

The avoided social cost valuation method was selected in this analysis.

(10) Environmental Benefit: Water Quality

The baseline water quality and expected water quality improvement values were not changed for the project. This project's water quality change does not occur in an estuary. The water quality change affects only local freshwater bodies that support recreation for 30% of the affected population. The median household income was calculated using the US Census and CPI inflation data. The number of households was calculated using the US Census and the ratio of the GSI management area to the total project city area.

(11) Environmental Benefit: Carbon

The carbon sequestration through rain gardens, bioretention, and wetlands model was used to calculate the carbon sequestration benefit. The NYCW eGRID region was selected to calculate energy savings. In addition, the tool uses the area of GSI practices to calculate carbon sequestered.

(12) Environmental Benefit: Improvements to Ecosystem Services

The tool uses the area of the GSI practices and the assumption that 80% of this area generates habitat creation. The area of the bioretention area was removed from this calculation since the sand filter is not expected to create habitat.

5.4.5 Results Dashboard

The net present value of the Phoenix, Arizona project's total benefits accrued over the study period are valued at $476,089 while the net present value of the total costs accrued over the study period are estimated at $806,978. Dividing the lifetime benefits by the lifetime costs gives a benefit-cost ratio of 0.590. This means that for every $1 invested into the project, the project is expected to return $0.590 in realized benefits.

Results are presented as Table 5-14 through Table 5-16.

Table 5-14. Phoenix, AZ – GSI TBL Tool Model Results: Volume.

Stormwater GSI Practice	Volume Required (CF)	Volume Provided (CF)
Permeable Pavement	6,857	6,720
Rain Garden	1,234	1,209
Total	**8,092**	**7,930**

Table 5-15. Phoenix, AZ – GSI TBL Tool Model Results: Lifecycle Costs.

Description	Present Value Cost (US Dollars)
Construction Cost	$ 659,233
Maintenance Cost	$ 100,548
Replacement Cost	$ 47,197
Total Lifecycle Cost	**$ 806,978**

Table 5-16. Phoenix, AZ – GSI TBL Tool Model Results: Co-Benefits.

Benefit Category	Benefit Description	Net Present Value of Benefit
Financial	Avoided Infrastructure Costs	$ 155,916
Financial	Avoided Replacement Costs	$ 250,000
Financial	Energy Savings	$ -
Social	Water Supply	$ 5,466
Social	Air Quality	$ 442
Social	Increased Property Values	$ 1,076
Social	Heat Stress Reduction	$ 17,586
Social	Recreation	$ 10,711
Social	Green Job Creation	$ 20,398
Environmental	Water Quality	$ 13,034
Environmental	Carbon	$ 682

Benefit Category	Benefit Description	Net Present Value of Benefit
Environmental	Improvements to Ecosystem Services	$ 778
Total Net Present Value of Benefits		**$ 476,089**

5.5 Comparison of Tools

A comparison of the volume, lifecycle costs, and co-benefits of the tools are shown in Table 5-17 through Table 5-19.

Table 5-17. Phoenix, AZ – Comparison of Stormwater Approach.

Description	Volume Provided (CF) CLASIC Tool	Volume Provided (CF) GSI TBL Tool
Permeable Pavement	21,944	6,720
Rain Garden	1,320	1,209
Volume Provided	**23,264**	**7,930**

Table 5-18. Phoenix, AZ – Comparison of Lifecycle Costs.

Description	CLASIC Tool (US Dollars)	GSI TBL Tool (US Dollars)
Construction Cost	$ 833,610	$ 659,233
Maintenance Cost	$ 169,875	$ 100,548
Replacement Cost	$ 47,197	$ 47,197
Lifecycle Cost	**$ 1,050,682**	**$ 806,978**

Table 5-19. Phoenix, AZ – Comparison of Co-Benefits.

Description	CLASIC Tool (Out of 5 Each or 15 Total)		GSI TBL Tool (US Dollars)	
Social Benefits	4.72	37%	$ 55,679	12%
Financial Benefits	3.83	30%	$ 405,916	85%
Environmental Benefits	4.29	33%	$ 14,494	3%
Total Benefits	**12.84**	**100%**	**$ 476,089**	**100%**

5.6 Key Takeaways

The following are key takeaways from the case study.

1. The tools do not use the same terminology as it relates to design storms, depths, practices, and volumes.
2. Stormwater volume is calculated differently in the tools. In CLASIC, stormwater volume is based on the surface area of the GSI practice and the depth available to store water in the ponding and filter media layers. A void space of 40% is assigned to open graded aggregate/stone and soil storage layers. In the GSI TBL Tool, stormwater volume is based on design depth to capture (feet) and impervious drainage area (square feet), with a factor of 0.98 applied. The GSI TBL Tool consistently provided slightly lower volumes due to the 0.98 factor.
3. The calculation for stormwater volume in permeable pavement systems accounted for the largest difference between the two tools. This is due to the minimum depth of stone required for pavement stability, which exceeded the design depth to capture in the case studies. In other words, permeable pavement systems can often handle a much larger storm event than the design depths attributed to GSI design.
4. The team experienced challenges with making modifications to the pre-populated design criteria in CLASIC. While the tool allowed for customizing the number of practices and drainage area, such modifications often caused the tool to malfunction. It was very challenging to customize the tool to fit the exact design parameters. For this reason, the team modified the design criteria to find a best fit within CLASIC.
5. Selecting the importance of co-benefits in the CLASIC tool requires the user to make assumptions based on their knowledge of the project. The CLASIC user manual could benefit from additional instructions, or future updates to the CLASIC tool could run the co-benefits analysis with more targeted user input based on project drivers, project location, or site-specific criteria.
6. Cost data in CLASIC is presented in both the “build scenarios” tab and within the final report. It appears that the costs presented in the build scenarios tab do not account for the number of practices within each design category and/or the discounted cost over the full study period. The costs listed in the advanced tab appear to be per GSI practice, not per

unit area or unit volume which is industry standard, and the basis of the GSI TBL Tool costing.

7. Practices that have class options (e.g., rain gardens, sand filters, infiltration trenches detention basin, and wet ponds) were found to range significantly in cost. For example, CLASIC notes that a small rain garden with a footprint of 100 square feet is approximately $122/ square foot, whereas a large rain garden with a footprint of 10,000 square feet is approximately $43/ square foot. This impact is an economy of scale effect.
8. The GSI TBL Tool required a much greater understanding of stormwater management design, benefits quantification, and economics than the CLASIC tool.
9. Both CLASIC and the GSI TBL tool account for vertical side slopes for rain garden and bioretention facilities, instead of sloped side slopes that is traditional for these types of practices. As a result, system volumes and footprints may be underestimated.
10. Based on the CLASIC outputs provided to the user and without additional information or calculations provided in the manual, it was difficult to verify the percent reduction in runoff and pollutant loads. The GSI TBL Tool does not provide outputs for pollutant load reductions.
11. The project boundary is not listed on the CLASIC output tab and seemed to disappear from the CLASIC data fields. As this parameter was needed for the GSI TBL Tool, it should be included in the CLASIC outputs.
12. The permeable pavement practice in the GSI TBL Tool is reported with a significantly lower volume capacity than CLASIC.
13. A project driver for the case study was noted to be reduction in heat stress. However, GSI TBL tool does not consider comfort but only extreme issues such as hospitalizations and deaths and typically needs a much larger study area to see impacts. Therefore, the benefit of the GSI practices for heat stress do not show a benefit.
14. The benefits of GSI to water quality for a separate sewer system are not accounted for in the co-benefits section for the CLASIC tool. Within the GSI TBL Tool, it would be helpful to include catch basin filter inserts or oil-water separators that would count as treatment for separate sewer systems.
15. It is unclear if the models account for sewer typology.

CHAPTER 6

Case Study #5: San Antonio, Texas

6.1 Overview

This case study highlights a project in San Antonio, Texas in the South Climate Region. The key project driver is water quality improvements. The case study includes the use of bioswales to manage 2.19 acres of impervious cover.

6.2 Background

The San Antonio River Basin extends from Kerr and Medina counties in central Texas southeast toward the Gulf of Mexico. Portions of the Upper San Antonio Watershed, located within the City of San Antonio, have not met water quality standards due to bacteria levels. The San Antonio River Authority received United States Environmental Protection Agency (EPA) funding through the Texas Commission on Environmental Quality (TCEQ) to create a Green Stormwater Infrastructure Master Plan (Master Plan) for portions of the Upper San Antonio River Watershed. The purpose of the Master Plan is to identify and study GSI projects to reduce stormwater runoff pollution and to address measures outlined in the Texas Non-Point Source Management Program. This case study explores the use of small median bioswales to improve water quality.

Design details were used to provide a comparison of WRF's CLASIC and GSI TBL tool outputs only and should not be relied upon for anything outside the scope of this research project.

Site 8 (Subbasin 560) was identified in the Master Plan to improve water quality of the San Antonio River Basin. This project includes the construction of bioswales within grassed medians of Sidney Brooks Drive and City Base Landing Road to manage runoff from the adjacent roadways. Figure 6-1 provides an overview of the project.

The main driver for this project is improvements to the water quality, often represented as an annual reduction in pollutant loadings for total suspended solids, phosphorus, nitrogen, and bacteria. Of particular interest for this case study is a reduction in bacteria. Key model inputs used for both tools are summarized in Table 6-1.

Table 6-1. San Antonio, TX – Key Model Inputs.

Feature	Value	Unit of Measurement
Average Annual Precipitation	31.1	Inches
Average Annual Runoff (CLASIC) or Annual Rainfall that Results in Runoff (GSI TBL Tool)	13.1	Inches
Cost Regionalization Factor	1	%
Annual Discount Factor (CLASIC) or Discount Rate (GSI TBL Tool)	3	%
Analysis Period	30	Years

An overview of the stormwater management approach is summarized in Table 6-2.

Table 6-2. San Antonio, TX – Stormwater Overview.

Design Parameter	Rain Garden
Impervious Drainage Area (Acres)	2.19
Impervious Drainage Area (Square Feet)	95,396
Proposed BMP Footprint (Square Feet)	6,000
Proposed Surface Storage Depth (Feet) [100% Porosity]	0.75
Proposed Subsurface Storage Depth (Feet) [40% Porosity]	2.00
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool) (Feet)	0.08
Volume Required (CF)	7,950
Volume Provided (CF)	9,300

6.3 CLASIC Model Overview

CLASIC includes icons on the left side of the screen to guide the user through the steps of the CLASIC Tool. Inputs for this case study have been presented in the same order as the CLASIC guide for ease of review.

6.3.1 Define Study Area

A rectangular-shaped area was selected for the project location using the draw on map function. This case study was run with a single subunit. Figure 6-1 illustrates the proposed project boundary.

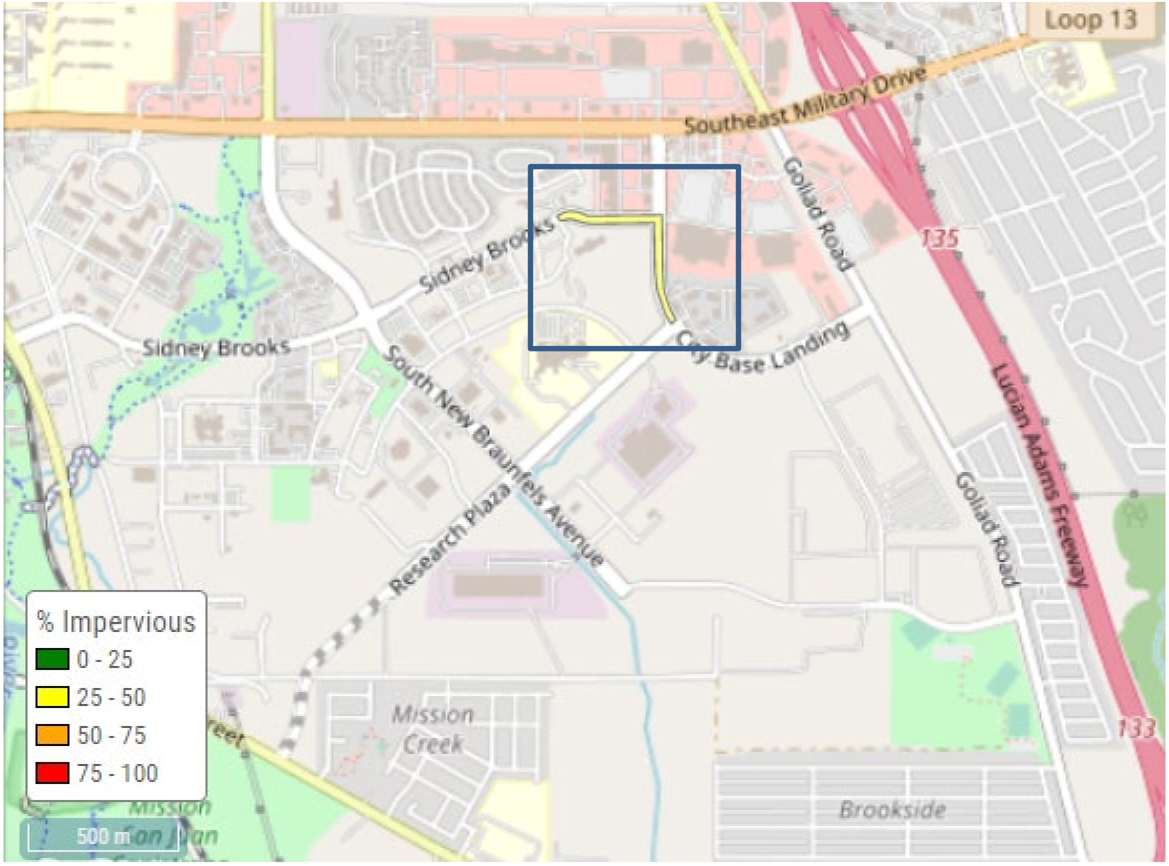
6.3.2 Select Climate Data

The San Antonio Airport precipitation station and Kelly Air Force Base evaporation station was chosen.

6.3.3 Define Model Defaults

No modifications were made to the model default values.

Figure 6-1. San Antonio, TX – Project Overview.



6.3.4 Build Scenarios

The rain garden practice was used for this case study. Design parameters are summarized as Table 6-3.

Table 6-3. San Antonio, TX – CLASIC Model Design Parameters – Rain Garden.

Design Parameter	Unit	Unit of Measurement
Class	Medium	Unitless
Surface Area (CLASIC) / BMP Size (GSI TBL Tool)	1,000	SF
Ponding Depth	9	Inches
Filter Media Depth (CLASIC) / Depth (GSI TBL Tool)	24	Inches
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	1	Inches
Number of Practices (CLASIC) / Number of BMPs (GSI TBL Tool)	6	Unitless
Total Captured [Impervious] Area (CLASIC) / Effective Impervious Area Managed (GSI TBL Tool)	2.19	Acres
Total Technology Area (CLASIC) / Calculated BMP Area (GSI TBL Tool)	6,000	SF
Total Volume Captured (CLASIC) / Volume Capacity by BMP Type (GSI TBL Tool)	9,300	CF
Years to Replacement	25	Years

6.3.5 Set Importance of Co-Benefits

Table 6-4 highlights the co-benefit factors that were identified as significant for this project. Inputs in this tab are used to develop the co-benefit analysis score. Please note that the assigned level of importance was developed by the research team based on their understanding of the project and tool inputs.

Table 6-4. San Antonio, TX – CLASIC Model Co-Benefit Analysis Importance Factors.

Co-Benefit Category	Co-Benefit	CLASIC Parameter Used for Estimation	Assigned Level of Importance
Financial	Increased Property Values	Reduction in Impervious Cover / Increase in Green Space	Somewhat Important
Financial	Reduced Costs from Illness	Increase in Plants, Trees, and Green Roofs	Somewhat Important
Financial	Avoided Costs from Combined Sewer Treatment	Combined Sewer Systems Only; Runoff Volume Reduction	Not Important
Financial	Reduced or Mitigated Impacts from Nuisance Floods	Runoff Volume Reduction	Medium Importance
Financial	Enhanced Building Energy Efficiency	Area of Green Roof	Not Important
Financial	Avoided Water Treatment	Volume of Stormwater Harvested	Not Important
Financial	Improvements to Employment Opportunities	Annual Maintenance Cost	Somewhat Important
Social	Health Benefits from Improvements to Air Quality	Increase in Plants, Trees, and Green Roofs	Somewhat Important
Social	Mental Health Improvements	Reduction in Impervious Cover / Increase in Green Space	Medium Importance
Social	Improvements to Thermal Health	Reduction in Impervious Cover / Increase in Green Space	Medium Importance
Social	Increased Supply from Harvested Stormwater	Volume of Stormwater Harvested	Not Important
Social	Increased Public Awareness of	Number of Stormwater Practices	Very Important

Co-Benefit Category	Co-Benefit	CLASIC Parameter Used for Estimation	Assigned Level of Importance
	Stormwater and Water Systems		
Social	Potential Avoided Social Strain Associated with Nuisance Flooding	Runoff Volume Reduction	Very Important
Environmental	Improvements to Ecosystem Services	Diversity of Vegetation	Very Important
Environmental	Increased Groundwater Flow	Runoff Volume Infiltrated	Somewhat Important
Environmental	Carbon Sequestration	Increase in Plants, Trees, and Green Roofs	Medium Importance

6.3.6 Set Targets

Targets were not included in the case study.

6.3.7 Results

A baseline scenario was not developed for this case study. Therefore, results will be compared to a "do nothing" scenario. Results are presented as Table 6-5 through Table 6-8.

Table 6-5. San Antonio, TX– CLASIC Model Results: Lifecycle Cost.

Description	Present Value Cost (US Dollars)
Construction Cost	$ 407,550
Maintenance Cost	$ 167,287
Replacement Cost	$ 100,031
Total Lifecycle Cost	**$ 674,868**

Table 6-6. San Antonio, TX – CLASIC Model Results: Co-Benefits.

Description	Co-Benefit Score (Out of 5 Each or 15 Total)
Social Benefits Score	3.82
Economic Score	3.33
Environmental Score	4.26
Total Score	**11.41**

Table 6-7. San Antonio, TX – CLASIC Model Results: Hydrologic Performance.

Description	Percentage Change from Baseline
Average Annual Runoff (Inches)	69.7% Decrease
Average Annual Infiltration (Inches)	48.1% Increase
Average Annual Evaporation (Inches)	66.2% Increase

Table 6-8. San Antonio, TX – CLASIC Model Results: Water Quality Performance.

Description	Percentage Change from Baseline
Total Suspended Solids	69.7% Reduction
Total Nitrogen	69.7% Reduction
Total Phosphorus	69.7% Reduction
Fecal Indicator Bacteria	69.7% Reduction

6.4 GSI TBL Model Overview

The GSI TBL tool includes a series of tabs within the Excel document, including key inputs, green stormwater infrastructure (GSI) scenario, costs timeline, and a range of co-benefits to explore. Inputs for this case study have been presented in the same order for ease of review.

6.4.1 Key Inputs

Key Inputs are summarized as Table 6-9.

Table 6-9. San Antonio, TX – GSI TBL Tool Key Inputs.

Key Input	Unit	Unit of Measurement
Annual Rainfall that Results in Runoff	13.1	Inches
Design Storm Percentile	80	Percentile
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	1	Inch
Management Area	4.87	Acres
Management Area	0.008	Square Miles
Population Density	2,876	People/Square Mile
Management Area Population	22	People
Climate Zone	South	Unitless

6.4.2 GSI Scenario

Table 6-10 provides a summary of GSI practice drainage area and design specifications.

Table 6-10. San Antonio, TX – GSI TBL Tool Model Design Parameters – Rain Garden.

Design Parameter	Unit	Unit of Measurement
Surface Area (CLASIC) / BMP Size (GSI TBL Tool)	1,000	SF
Ponding Depth	9	Inches
Filter Media Depth (CLASIC) / Depth (GSI TBL Tool)	24	Inches
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	1	Inches
Number of Practices (CLASIC) / Number of BMPs (GSI TBL Tool)	5	Unitless
Total Captured [Impervious] Area (CLASIC) / Effective Impervious Area Managed (GSI TBL Tool)	2.19	Acres

Design Parameter	Unit	Unit of Measurement
Total Technology Area (CLASIC) / Calculated BMP Area (GSI TBL Tool)	5,026	SF
Run-on-Ratio (Impervious Area Managed / BMP Area)	18.98	Unitless
Total Volume Captured (CLASIC) / Volume Capacity by BMP Type (GSI TBL Tool)	7,791	CF
Annual Runoff Volume	81,647	CF / Year
Annual Runoff Volume	1.87	Acre-Feet / Year
Annual Runoff Volume	610,717	Gallons / Year
Years to Replacement	25	Years

6.4.3 Costs Timeline

Replacement costs are not automatically calculated for the GSI TBL Tool. For a more direct comparison, replacement costs and timelines were pulled from the CLASIC tool. Replacement costs were added at 25 years for the rain garden.

6.4.4 Benefit Calculations

The GSI TBL Tool monetizes benefits across three benefit categories: financial, social, and environmental benefits. Each category is outlined in more detail below and net present values of the benefits are summarized in Table 6-16.

(1) Financial Benefit: Avoided Infrastructure Costs

The model for avoided cost associated with stormwater pumping and treatment was applied using the annual runoff volume retained in the GSI practices. The model assumes that 30% of this retained volume will result in avoided pumping and treatment.

(2) Financial Benefit: Avoided Replacement Costs

The model for avoided replacement costs for the use of permeable pavement was applied using the area of permeable pavement. The model assumes standard maintenance costs for traditional asphalt streets and parking lots, and that the permeable pavement will be used to replace 20% of an asphalt parking lot.

(3) Financial Benefit: Energy Savings

The volume of stormwater retained annually did not generate an energy savings benefit. Therefore, this benefit did not generate a credit.

(4) Social Benefit: Water Supply

The model for groundwater recharge benefit was applied using the annual runoff volume managed. The model assumes 50% infiltration to water supply aquifers and a 77.5% recharge efficiency rate.

(5) Social Benefit: Air Quality

The RMPA eGRID region and Rocky Mountains AVERT region were used to calculate energy savings from stormwater pumping and treatment. In addition, the model uses the area of vegetation from the rain garden and bioretention facility to calculate air pollutant removal benefits.

(6) Social Benefit: Property Values

Option 2 – Baseline Property Value was selected for this benefit calculation. Baseline counts and aggregate values of units by structure type were pulled from US Census data. The property value benefit was estimated based on the percentage of practice area within the project study area. The model assumes that 20% of properties are excluded due to higher property values.

(7) Social Benefit: Heat Stress

The change in days where the city's temperature is above the minimum mortality temperature does not result in any reductions in heat-related deaths, emergency room visits, or hospitalizations. Therefore, the rain garden does not generate a heat stress credit.

(8) Social Benefit: Recreation

The project doesn't create any pocket parks, stormwater parks (e.g., parks that have stormwater management as a major component of the park upgrade), or wetland area recreation. However, the area does provide general neighborhood greening. It was determined that neighborhood greening occurs 4 months a year, and 100% of the management area that benefits from general neighborhood greening will support recreational activity.

(9) Social Benefit: Green Jobs

The avoided social cost valuation method was selected in this analysis.

(10) Environmental Benefit: Water Quality

The baseline water quality and expected water quality improvement values were not changed for the project. This project's water quality change does not occur in an estuary. The water quality change affects only local freshwater bodies that support recreation for 30% of the affected population. The median household income was calculated using the US Census and CPI inflation data. The number of households was calculated using the US Census and the ratio of the GSI management area to the total project city area.

(11) Environmental Benefit: Carbon

The carbon sequestration through rain gardens, bioretention, and wetlands model was used to calculate the carbon sequestration benefit. The NYCW eGRID region was selected to calculate energy savings. In addition, the tool uses the area of GSI practices to calculate carbon sequestered.

(12) Environmental Benefit: Improvements to Ecosystem Services
The tool uses the area of the GSI practices and the assumption that 80% of this area generates habitat creation. The area of the bioretention area was removed from this calculation since the sand filter is not expected to create habitat.

6.4.5 Results Dashboard

The net present value of the San Antonio, Texas project's total benefits accrued over the study period are valued at $52,004 while the net present value of the total costs accrued over the study period are estimated at $422,090. Dividing the lifetime benefits by the lifetime costs gives a benefit-cost ratio of 0.123. This means that for every $1 invested into the project, the project is expected to return $0.123 in realized benefits.

Results are presented as Table 6-11 through Table 6-13.

Table 6-11. San Antonio, TX – GSI TBL Tool Model Results: Volume.

Stormwater GSI Practice	Volume Required (CF)	Volume Provided (CF)
Rain Garden	7,950	7,791
Total	**7,950**	**7,791**

Table 6-12. San Antonio, TX – GSI TBL Tool Model Results: Lifecycle Costs.

Description	Present Value Cost (US Dollars)
Construction Cost	$ 202,806
Maintenance Cost	$ 119,253
Replacement Cost	$ 100,031
Total Lifecycle Cost	**$ 422,090**

Table 6-13. San Antonio, TX – GSI TBL Tool Model Results: Co-Benefits.

Benefit Category	Benefit Description	Net Present Value of Benefit
Financial	Avoided Infrastructure Costs	$ 4,428
Financial	Avoided Replacement Costs	$ -
Financial	Energy Savings	$ -
Social	Water Supply	$ 16,917
Social	Air Quality	$ 3,686
Social	Increased Property Values	$ 646
Social	Heat Stress Reduction	$ -
Social	Recreation	$ 6,933
Social	Green Job Creation	$ 6,759
Environmental	Water Quality	$ 6,603
Environmental	Carbon	$ 2,580
Environmental	Improvements to Ecosystem Services	$ 3,452
Total Net Present Value of Benefits		**$ 52,004**

6.5 Comparison of Tools

A comparison of the volume, lifecycle costs, and co-benefits of the tools are shown in Table 6-14 to Table 6-16.

Table 6-14. San Antonio, TX – Comparison of Volume.

Description	Volume Provided (CF) CLASIC Tool	Volume Provided (CF)
		GSI TBL Tool
Rain Garden	13,200	12,913
Wet Pond	10,400,000	10,102,305
Volume Provided	**10,413,200**	**10,115,218**

Table 6-15. San Antonio, TX – Comparison of Lifecycle Costs.

Description	CLASIC Tool (US Dollars)	GSI TBL Tool (US Dollars)
Construction Cost	$ 407,550	$ 202,806
Maintenance Cost	$ 167,287	$ 119,253
Replacement Cost	$ 100,031	$ 100,031
Lifecycle Cost	**$ 674,868**	**$ 422,090**

Table 6-16. San Antonio, TX – Comparison of Co-Benefits.

Description	CLASIC Tool (Out of 5 Each or 15 Total)		GSI TBL Tool (US Dollars)	
Social Benefits	3.82	33%	$ 34,941	67%
Financial Benefits	3.33	29%	$ 4,428	9%
Environmental Benefits	4.26	37%	$ 12,635	24%
Total Benefits	**11.41**	**100%**	**$ 52,004**	**100%**

6.6 Key Takeaways

The following are key takeaways from the case study.

1. The tools do not use the same terminology as it relates to design storms, depths, practices, and volumes.
2. Stormwater volume is calculated differently in the tools. In CLASIC, stormwater volume is based on the surface area of the GSI practice and the depth available to store water in the ponding and filter media layers. A void space of 40% is assigned to open graded aggregate/stone and soil storage layers. In the GSI TBL Tool, stormwater volume is based on design depth to capture (feet) and impervious drainage area (square feet), with a factor of 0.98 applied. The GSI TBL Tool consistently provided slightly lower volumes due to the 0.98 factor.
3. The team experienced challenges with making modifications to the pre-populated design criteria in CLASIC. While the tool allowed for customizing the number of practices and drainage area, such modifications often caused the tool to malfunction. It was very challenging to customize the tool to fit the exact design parameters. For this reason, the team modified the design criteria to find a best fit within CLASIC.
4. Selecting the importance of co-benefits in the CLASIC tool requires the user to make assumptions based on their knowledge of the project. The CLASIC user manual could benefit from additional instructions, or future updates to the CLASIC tool could run the co-benefits analysis with more targeted user input based on project drivers, project location, or site-specific criteria.
5. Cost data in CLASIC is presented in both the “build scenarios” tab and within the final report. It appears that the costs presented in the build scenarios tab do not account for the number within each design category and/or the discounted cost over the full study period. The costs listed in the advanced tab appear to be per GSI practice, not per unit area or unit volume which is industry standard, and the basis of the GSI TBL Tool costing.
6. Practices that have class options (e.g., rain gardens, sand filters, infiltration trenches detention basin, and wet ponds) were found to range significantly in cost. For example, CLASIC notes that a small rain garden with a footprint of 100 square feet is approximately $122/ square foot, whereas a large rain garden with a footprint of 10,000 square feet is approximately $43/ square foot. This impact is an economy of scale effect.
7. The GSI TBL Tool required a much greater understanding of stormwater management design, benefits quantification, and economics than the CLASIC tool.
8. Both CLASIC and the GSI TBL tool account for vertical side slopes for rain garden and bioretention facilities, instead of sloped side slopes that is traditional for these types of practices. As a result, system volumes and footprints may be underestimated.
9. Based on the CLASIC outputs provided to the user and without additional information or calculations provided in the manual, it was difficult to verify the percent reduction in runoff and pollutant loads. The GSI TBL Tool does not provide outputs for pollutant load reductions.
10. The project boundary is not listed on the CLASIC output tab and seemed to disappear from the CLASIC data fields. As this parameter was needed for the GSI TBL Tool, it should be included in the CLASIC outputs.

11. This case study was used to highlight a smaller scale system with one stormwater management typology. The team expected that the construction and maintenance costs would have been more similar.

CHAPTER 7

Case Study #6: Sun Valley, California

7.1 Overview

This case study highlights a project in Sun Valley, California in the West Climate Region. The key project drivers are water conservation and urban heat island reduction. The case study includes the use of subsurface trenches and wet ponds to manage 353.65 acres of impervious cover.

7.2 Background

Sun Valley, California is within the San Fernando Valley, approximately 14 miles northwest of downtown Los Angeles. This highly developed area relies heavily on overland conveyance of stormwater runoff and does not have a major underground stormwater management drainage system. For this reason, street flooding and property damage is a common occurrence, even during minor storm events.

Sun Valley receives approximately 17 inches of precipitation each year, with much of the rainfall occurring between November and April. Located within the San Fernando Groundwater Basin, Sun Valley provides a significant source of drinking water for the Los Angeles Region, accounting for 15 percent of drinking water for the City of Los Angeles alone. Proper management of stormwater is critical to maintain the water supply in this semi-arid region. This case study explores the use of a large-scale infiltration system to reduce flood risk and encourage groundwater recharge.

Three projects – Rory M Shaw Wetlands Park, Sun Valley Park, and Sun Valley Upper Storm Drain Project – are combined for this case study since they are hydraulically connected. The projects are managed by the Los Angeles County Flood Control District, the City of Los Angeles, and the Sun Valley Watershed Stakeholders Group. Identified in the Sun Valley Watershed Management Plan, the purpose of the projects is to solve reoccurring flooding problems in the Sun Valley Watershed with multi-purpose solutions. While flood management and water conservation are the main project drivers, the projects also include co-benefits such as improved recreation, wildlife habitat creation, improved water quality, and improved air quality.

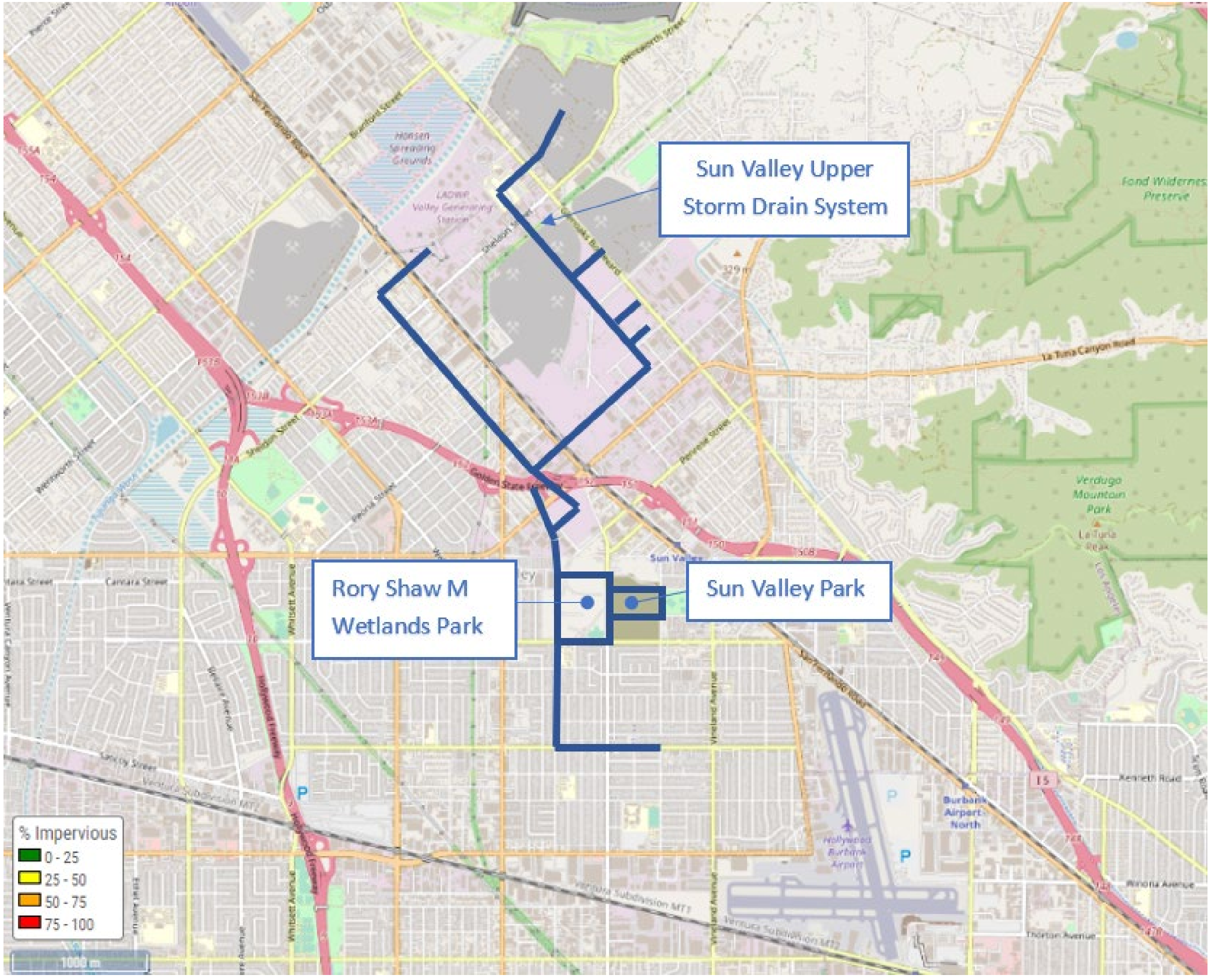
Design details were developed from a review of publicly available data and may not provide an accurate representation of the projects. This information was used to provide a comparison of the Water Research Foundation CLASIC and GSI TBL tool outputs only and should not be relied upon for anything outside the scope of this research project.

The Sun Valley Park project was constructed in 2006. The project includes two large underground infiltration basins on a 17-acre site, buried beneath soccer and baseball fields, to manage a tributary drainage area of approximately 21 acres from the park and surrounding streets. Pretreatment is provided with a water quality treatment system to remove suspended solids and heavy metals prior to directing the water to the underground infiltration basins for groundwater recharge.

The Rory M Shaw Wetlands Park project, in design, proposes to convert a 46-acre engineered inert landfill, immediately adjacent to the Sun Valley Park, into a multi-purpose wetlands park with a detention pond (21-acres), wetland area (10-acres), and recreational space (15-acres). The recreational space will include trails, picnic tables, a soccer field, open play area, tennis courts, basketball courts, educational signage, bathrooms, and playgrounds.

The tributary drainage area to the Rory M Shaw Wetlands Park is estimated to be 929 acres. Routing of this significant drainage area requires the construction of 4.75 miles of new storm drainage system, funding through a separate project called the Sun Valley Upper Storm Drain project. New storm drainage is proposed along major streets in the Sun Valley Community, including Glenoaks Boulevard, San Fernando Road, Tuxford Street, and Tujunga Avenue. Figure 7-1 provides an overview of the project.

Figure 7-1. Sun Valley, CA – Project Overview.



Within the Rory M Shaw Wetlands Park, a 21-acre detention pond will provide capacity to hold stormwater collected from the upstream tributary areas of the Sun Valley Community. The captured stormwater will then enter a 10-acre wetland area that will provide water quality treatment. Finally, treated stormwater will be pumped to two existing underground infiltration basins within the Sun Valley Park for groundwater recharge. The footprint of the existing underground infiltration basins has been estimated as 70,000 square feet (1.61 acres) based on an overview map within the Sun Valley Watershed Management Plan. The entire project is expected to provide approximately 590 AF/year of groundwater recharge through infiltration.

This case study represents a variety of GSI practices working in series to provide storage and attenuation (detention basin), water quality treatment (constructed wetlands and water quality filtration system), and finally infiltration (underground infiltration). Since the WRF CLASIC and GSI TBL tools do not provide an option for routing of GSI practices in series, the research team modeled the system as an infiltration based GSI practice to quantify the volume managed/infiltrated. Figure 7-2 provides a detailed overview of the project components.

Figure 7-2. Sun Valley, CA – Stormwater Overview.

Key model inputs used for both tools are summarized in Table 7-1.

Table 7-1. Sun Valley, CA – Key Model Inputs.

Feature	Value	Unit of Measurement
Average Annual Precipitation	17.1	Inches
Average Annual Runoff (CLASIC) or Annual Rainfall that Results in Runoff (GSI TBL Tool)	8.2	Inches
Cost Regionalization Factor	1.14	%
Annual Discount Factor (CLASIC) or Discount Rate (GSI TBL Tool)	3	%
Analysis Period	30	Years

Due to model limitations, the case study described above needed to be simplified – see key takeaways for additional discussion. The project team assumed that the original concept design involved storage in 31-acre footprint area, an existing 1.7-acre underground infiltration system, and 15-acre park and a total drainage area of 950 acres. This would align with the purpose of the tools to use them at a concept level and the final design would have been determined after using the CLASIC and GSI TBL Tool. An overview of the stormwater management approach is summarized in Table 7-2.

Table 7-2. Sun Valley, CA – Stormwater Overview.

Design Parameter	Subsurface Infiltration Trench	Wet Pond
Impervious Drainage Area (Acres)	6.58	347.07
Impervious Drainage Area (Square Feet)	286,625	15,118,369
Proposed BMP Footprint (Square Feet)	70,000	1,348,600
Proposed Surface Storage Depth (Feet) [100% Porosity]	0.00	8.00
Proposed Subsurface Storage Depth (Feet) [40% Porosity]	6.00	0.00
Permanent Pool Depth (Feet) [0% Porosity]	0.00	10.00
Permanent Pool Surface Area (Square Feet)	0.00	865,150.00
Top of Pond Surface Area (Square Feet)	0.00	1,348,600.00

Design Parameter	Subsurface Infiltration Trench	Wet Pond
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool) (Feet)	0.58	0.58
Volume Required (CF)	167,198	8,819,049
Volume Provided (CF)	168,000	8,855,000

7.3 CLASIC Model Overview

CLASIC is a screening tool that utilizes lifecycle cost framework to support the planning of green, hybrid green-gray, and gray infrastructure scenarios at the community, watershed, or neighborhood scale. The tool is hosted on a cloud-based web platform and integrated with GIS and national databases to upload data for the project area.

Users are guided through a series of steps within CLASIC to identify the project location and climate data. The user can then develop scenarios based on practices and/or changes to climate and land use. The tool estimates lifecycle cost, water quality and hydrologic performance, and a relative score of environmental, social, and financial benefits. CLASIC includes icons on the left side of the screen to guide the user through the steps of the CLASIC Tool. Inputs for this case study have been presented in the same order for ease of review.

7.3.1 Select Area

The CLASIC model evaluates the drainage area characteristics of the tributary drainage areas. For this reason, delineation of the project boundary must include the tributary drainage area, not just the anticipated project location. A rectangular shaped boundary was utilized to capture the new storm drainage system. Where a GIS shapefile is available, that could be utilized for a more accurate representation of the tributary drainage characteristics.

The next step is to identify the subunits. The analysis can be conducted with a single subunit or with several subunits, such as US census block, block group, and tracts. US census tracts are the largest subunit selection and blocks are the smallest. This case study was run with a single subunit. Figure 7-3 illustrates the proposed project area.

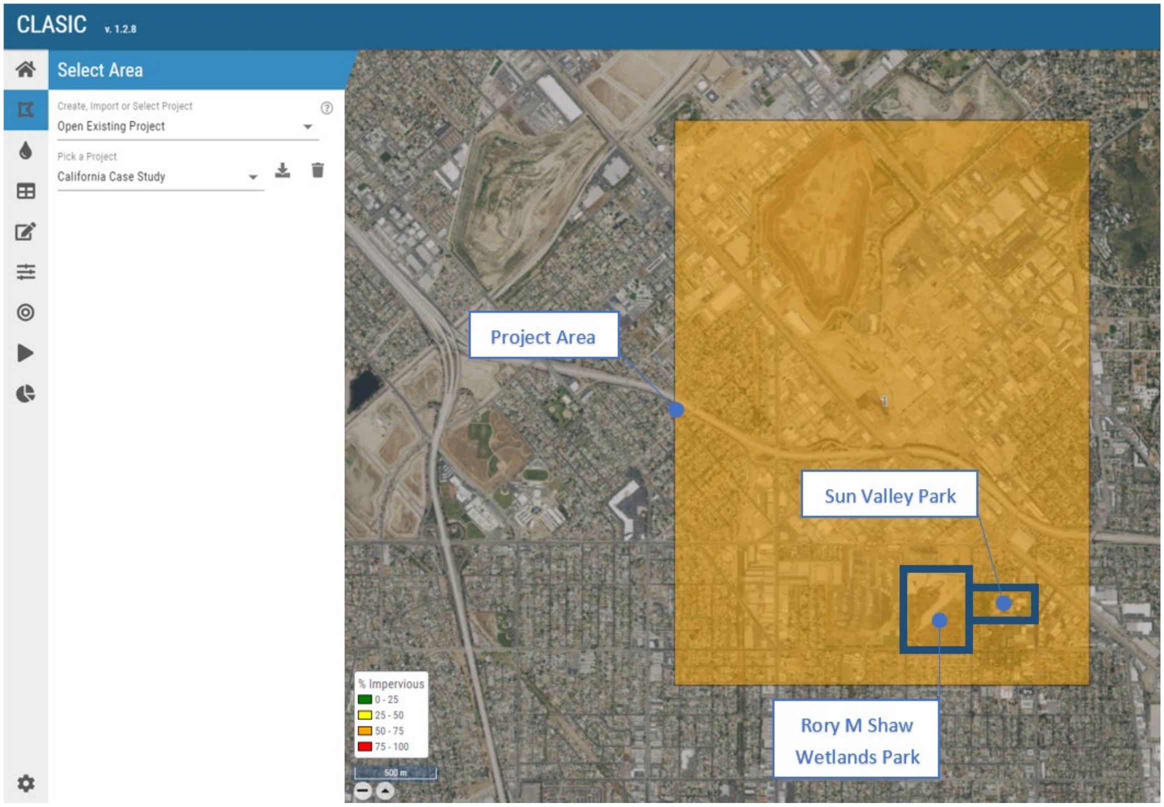
7.3.2 Climate Data

The climate data tab provides drop down menus to select local precipitation and evaporation stations. The Burbank Valley Pump Plant precipitation station and the San Fernando evaporation stations were chosen.

7.3.3 Model Defaults

The model defaults tab allows more experienced users to review and modify default parameters within the model. Drop-down menus are available for modifications to the subunits, water quality inputs, overland flow characteristics, infiltration, GSI practice effluent, and lifecycle cost data. No modifications were made to the model default values.

Figure 7-3. Sun Valley, CA – CLASIC Screenshot of Study Area.


CLASIC v. 1.2.8

Select Area

Create, Import or Select Project: Open Existing Project

Pick a Project: California Case Study

7.3.4 Build Scenarios

The build scenarios tab allows the user to develop scenarios of practices and/or changes to climate and land use. This allows the model to be modified to reflect a range of future scenarios, such as increased impervious cover or different climate change predictions. No changes were made to the future scenarios.

CLASIC includes drop-down menus for the following practices: rain garden, sand filter, infiltration trench, detention basin, wet pond, stormwater harvesting, storage vault, permeable pavement, disconnection, and green roofs. Note, wetlands are not one of the options to select within CLASIC.

The main drivers for this project are flood risk reduction and water conservation benefits. The key performance indicators are therefore volume of stormwater captured and volume of annual groundwater recharge. After a review of the available practices, a large detention basin was chosen since it represents the largest of the practices with the ability to account for both storage and infiltration.

Within the pre-populated design criteria for the large detention basin, the following parameters can be adjusted within the main screen: seepage rate, drain time, percent impervious area captured, and depth to capture.

For comparison with the WRF GSI TBL tool, total capture area and GSI practice footprint were the parameters of specific interest to confirm.

Total captured area was set to 950 acres by adjusting the percent impervious area captured to 82.677 within the GSI practice tab, as the project boundary exceeded the ideal 950 acres. Adjustments to the depth to capture and number of practices were used to adjust the total volume captured. A depth to capture of 2.5 inches resulted in 11 large detention basin practices with a total GSI practice area of 30.96 acres and a total volume captured of 203.28 acre-feet. While this is not a perfect match with the data presented in Table 7-2, it was the best fit with the available options within the tool. A summary of the CLASIC design parameters is summarized as Table 7-3 and Table 7-4.

Table 7-3. Sun Valley, CA – CLASIC Model Design Parameters – Subsurface Infiltration Trench.

Design Parameter	Unit	Unit of Measurement
Class	Large	Unitless
Surface Area (CLASIC) / BMP Size (GSI TBL Tool)	2,000	SF
Ponding Depth	0	Inches
Filter Media Depth (CLASIC) / Depth (GSI TBL Tool)	72	Inches
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	0	Inches
Number of Practices (CLASIC) / Number of BMPs (GSI TBL Tool)	35	Unitless
Total Captured [Impervious] Area (CLASIC) / Effective Impervious Area Managed (GSI TBL Tool)	6.58	Acres
Total Technology Area (CLASIC) / Calculated BMP Area (GSI TBL Tool)	70,000	SF
Total Volume Captured (CLASIC) / Volume Capacity by BMP Type (GSI TBL Tool)	168,000	CF
Years to Replacement	25	Years

Table 7-4. Sun Valley, CA – CLASIC Model Design Parameters – Wet Pond.

Design Parameter	Unit	Unit of Measurement
Class	Large	Unitless
Basin Volume	805,000	CF
Top Surface Area (CLASIC) / BMP Size (GSI TBL Tool)	122,600	SF

Design Parameter	Unit	Unit of Measurement
Permanent Pool Surface Area	78,650	SF
Basin Depth (CLASIC) / Ponding Depth (GSI TBL Tool)	96	Inches
Permanent Pool Depth	120	Inches
Permanent Pool Volume	760,000	CF
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	7	Inches
Number of Practices (CLASIC) / Calculated BMP Area (GSI TBL Tool)	11	Unitless
Total Captured [Impervious] Area (CLASIC) / Effective Impervious Area Managed (GSI TBL Tool)	347.07	Acres
Total Technology Area (CLASIC) / Calculated BMP Area (GSI TBL Tool)	1,348,600	SF
Total Volume Captured (CLASIC) / Volume Capacity by BMP Type (GSI TBL Tool)	8,855,000	CF
Years to Replacement	35	Years

7.3.5 Set Importance of Co-Benefits

Table 7-5 highlights the co-benefit factors that were identified as significant for this project. Inputs in this tab are used to develop the co-benefit analysis score. Please note that the assigned level of importance was developed by the research team based on their understanding of the project and tool inputs.

Table 7-5. Sun Valley, CA – CLASIC Model Co-Benefit Analysis Importance Factors.

Co-Benefit Category	Co-Benefit	CLASIC Parameter Used for Estimation	Assigned Level of Importance
Financial	Increased Property Values	Reduction in Impervious Cover / Increase in Green Space	Medium Importance
Financial	Reduced Costs from Illness	Increase in Plants, Trees, and Green Roofs	Medium Importance
Financial	Avoided Costs from Combined Sewer	Combined Sewer Systems Only; Runoff Volume	Not Important

Co-Benefit Category	Co-Benefit	CLASIC Parameter Used for Estimation	Assigned Level of Importance
	Treatment	Reduction	
Financial	Reduced or Mitigated Impacts from Nuisance Floods	Runoff Volume Reduction	Very Important
Financial	Enhanced Building Energy Efficiency	Area of Green Roof	Not Important
Financial	Avoided Water Treatment	Volume of Stormwater Harvested	Very Important
Financial	Improvements to Employment Opportunities	Annual Maintenance Cost	Very Important
Social	Health Benefits from Improvements to Air Quality	Increase in Plants, Trees, and Green Roofs	Medium Importance
Social	Mental Health Improvements	Reduction in Impervious Cover / Increase in Green Space	Very Important
Social	Improvements to Thermal Health	Reduction in Impervious Cover / Increase in Green Space	Very Important
Social	Increased Supply from Harvested Stormwater	Volume of Stormwater Harvested	Very Important
Social	Increased Public Awareness of Stormwater and Water Systems	Number of Stormwater Practices	Very Important
Social	Potential Avoided Social Strain Associated with Nuisance Flooding	Runoff Volume Reduction	Very Important

Co-Benefit Category	Co-Benefit	CLASIC Parameter Used for Estimation	Assigned Level of Importance
Environmental	Improvements to Ecosystem Services	Diversity of Vegetation	Very Important
Environmental	Increased Groundwater Flow	Runoff Volume Infiltrated	Very Important
Environmental	Carbon Sequestration	Increase in Plants, Trees, and Green Roofs	Medium Importance

7.3.6 Set Targets

Targets were not included in the case study.

7.3.7 Results

A baseline scenario was not developed for this case study. Therefore, results will be compared to a “do nothing” scenario. Results are presented as Table 7-6 through Table 7-10.

Table 7-6. Sun Valley, CA – CLASIC Model Results: Volume.

Stormwater GSI Practice	Volume Required (CF)	Volume Provided (CF)
Subsurface Infiltration Trench	167,198	168,000
Wet Pond	8,819,049	8,855,000
Total	**8,986,247**	**9,023,000**

Table 7-7. Sun Valley, CA – CLASIC Model Results: Lifecycle Costs.

Description	Present Value Cost (US Dollars)
Construction Cost	$ 9,373,848
Maintenance Cost	$ 6,727,583
Replacement Cost	$ 1,095,420
Total Lifecycle Cost	**$ 17,196,851**

Table 7-8. Sun Valley, CA – CLASIC Model Results: Co-Benefits.

Description	Co-Benefit Score (Out of 5 Each or 15 Total)
Social Benefits Score	1.04
Economic Score	1.25
Environmental Score	0.36
Total Score	**2.65**

Table 7-9. Sun Valley, CA – CLASIC Model Results: Hydrologic Performance.

Description	Percentage Change from Baseline
Average Annual Runoff (Inches)	5% Increase[1]
Average Annual Infiltration (Inches)	6.1% Decrease[1]
Average Annual Evaporation (Inches)	4% Increase

[1] The results of the hydrologic performance in this table are not what was expected, as the results show an increase in annual runoff and a decrease in annual infiltration. The opposite was expected given the large storage volume provided with the wet pond and the addition of infiltration-based practices via the subsurface infiltration trench. The team acknowledges that there appears to be an issue with the model but obtained same results when model was rerun.

Table 7-10. Sun Valley, CA – CLASIC Model Results: Water Quality Performance.

Description	Percentage Change from Baseline
Total Suspended Solids	53.2% Reduction
Total Nitrogen	30.8% Reduction
Total Phosphorus	40.1% Reduction
Fecal Indicator Bacteria	50.5% Reduction

7.4 GSI TBL Tool Overview

The GSI TBL tool includes a series of tabs within the Excel document, including key inputs, green stormwater infrastructure (GSI) scenario, costs timeline, and a range of co-benefits to explore. Inputs for this case study have been presented in the same order for ease of review.

7.4.1 Key Inputs

Key Inputs are summarized as Table 7-11.

Table 7-11. Sun Valley, CA – GSI TBL Tool Key Inputs.

Key Input	Unit	Unit of Measurement
Annual Rainfall that Results in Runoff	8.2	Inches
Design Storm Percentile	95	Percentile
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	7	Inch
Management Area	925	Acres
Management Area	1.445	Square Miles
Population Density	8,048	People/Square Mile
Management Area Population	11,632	People
Climate Zone	Southern California Coast	Unitless

7.4.2 GSI Scenario

Table 7-12 and Table 7-13 provide a summary of GSI practice drainage area and design specifications. The subsurface infiltration trench was modeled as a bioretention facility because it allowed for the closest comparison of data inputs.

Table 7-12. Sun Valley, CA – GSI TBL Tool Model Design Parameters – Bioretention (Subsurface Infiltration Trench).

Design Parameter	Unit	Unit of Measurement
Surface Area (CLASIC) / BMP Size (GSI TBL Tool)	2,000	SF
Ponding Depth	0	Inches
Filter Media Depth (CLASIC) / Depth (GSI TBL Tool)	72	Inches
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	7	Inches
Number of Practices (CLASIC) / Number of BMPs (GSI TBL Tool)	34	Unitless

Design Parameter	Unit	Unit of Measurement
Total Captured [Impervious] Area (CLASIC) / Effective Impervious Area Managed (GSI TBL Tool)	6.58	Acres
Total Technology Area (CLASIC) / Calculated BMP Area (GSI TBL Tool)	68,272	SF
Run-on-Ratio (Impervious Area Managed / BMP Area)	4.20	Unitless
Total Volume Captured (CLASIC) / Volume Capacity by BMP Type (GSI TBL Tool)	163,854	CF
Annual Runoff Volume	182,346	CF / Year
Annual Runoff Volume	4.19	Acre-Feet / Year
Annual Runoff Volume	1,363,947	Gallons / Year
Years to Replacement	25	Years

Table 7-13. Sun Valley, CA – GSI TBL Tool Model Design Parameters – Wet Pond.

Design Parameter	Unit	Unit of Measurement
Surface Area (CLASIC) / BMP Size (GSI TBL Tool)	168,000	SF
Ponding Depth	96	Inches
Filter Media Depth (CLASIC) / Depth (GSI TBL Tool)	0	Inches
Depth to Capture (CLASIC) / Design Storm Depth (GSI TBL Tool)	7	Inches
Number of Practices (CLASIC) / Number of BMPs (GSI TBL Tool)	11	Unitless
Total Captured [Impervious] Area (CLASIC) / Effective Impervious Area Managed (GSI TBL Tool)	347.07	Acres

Design Parameter	Unit	Unit of Measurement
Total Technology Area (CLASIC) / Calculated BMP Area (GSI TBL Tool)	1,080,333	SF
Run-on-Ratio (Impervious Area Managed / BMP Area)	14.0	Unitless
Total Volume Captured (CLASIC) / Volume Capacity by BMP Type (GSI TBL Tool)	8,642,668	CF
Annual Runoff Volume	9,618,055	CF / Year
Annual Runoff Volume	220.80	Acre-Feet / Year
Annual Runoff Volume	71,943,048	Gallons / Year
Years to Replacement	35	Years

7.4.3 Costs Timeline

Replacement costs are not automatically calculated for the GSI TBL Tool. For a more direct comparison, replacement costs and timelines were pulled from the CLASIC tool. Replacement costs were added at 25 years for the bioretention facility (subsurface infiltration trench) and at 35 years for the wet pond.

7.4.4 Benefit Calculations

The GSI TBL Tool monetizes benefits across three benefit categories: financial, social, and environmental benefits. Each category is outlined in more detail below and net present values of the benefits are summarized in Table 7-16.

(1) Financial Benefit: Avoided Infrastructure Costs

The model for avoided cost associated with stormwater pumping and treatment was applied using the annual runoff volume retained in the GSI practices. The model assumes that 30% of this retained volume will result in avoided pumping and treatment.

(2) Financial Benefit: Avoided Replacement Costs

The model for avoided replacement costs for the use of permeable pavement was applied using the area of permeable pavement. The model assumes standard maintenance costs for traditional asphalt streets and parking lots, and that the permeable pavement will be used to replace 20% of an asphalt parking lot.

(3) Financial Benefit: Energy Savings

The volume of stormwater retained annually did not generate an energy savings benefit. Therefore, this benefit did not generate a credit.

(4) Social Benefit: Water Supply

The model for groundwater recharge benefit was applied using the annual runoff volume managed. The model assumes 50% infiltration to water supply aquifers and a 77.5% recharge efficiency rate.

(5) Social Benefit: Air Quality

The RMPA eGRID region and Rocky Mountains AVERT region were used to calculate energy savings from stormwater pumping and treatment. In addition, the model uses the area of vegetation from the rain garden and bioretention facility to calculate air pollutant removal benefits.

(6) Social Benefit: Property Values

Option 2 – Baseline Property Value was selected for this benefit calculation. Baseline counts and aggregate values of units by structure type were pulled from US Census data. The property value benefit was estimated based on the percentage of GSI practice area within the project study area. The model assumes that 20% of properties are excluded due to higher property values.

(7) Social Benefit: Heat Stress

The change in days where the city's temperature is above the minimum mortality temperature does not result in any reductions in heat-related deaths, emergency room visits, or hospitalizations. Therefore, the rain garden does not generate a heat stress credit.

(8) Social Benefit: Recreation

The project doesn't create any pocket parks, stormwater parks (e.g., parks that have stormwater management as a major component of the park upgrade), or wetland area recreation. However, the area does provide general neighborhood greening. It was determined that neighborhood greening occurs 4 months a year, and 100% of the management area that benefits from general neighborhood greening will support recreational activity.

(9) Social Benefit: Green Jobs

The avoided social cost valuation method was selected in this analysis.

(10) Environmental Benefit: Water Quality

The baseline water quality and expected water quality improvement values were not changed for the project. This project's water quality change does not occur in an estuary. The water quality change affects only local freshwater bodies that support recreation for 30% of the affected population. The median household income was calculated using the US Census and CPI inflation data. The number of households was calculated using the US Census and the ratio of the GSI management area to the total project city area.

(11) Environmental Benefit: Carbon

The carbon sequestration through rain gardens, bioretention, and wetlands model was used to calculate the carbon sequestration benefit. The NYCW eGRID region was selected to calculate energy savings. In addition, the tool uses the area of GSI practices to calculate carbon sequestered.

(12) Environmental Benefit: Improvements to Ecosystem Services

The tool uses the area of the GSI practices and the assumption that 80% of this area generates habitat creation. The area of the bioretention area was removed from this calculation since the sand filter is not expected to create habitat.

7.4.5 Results Dashboard

The net present value of the Sun Valley, California project's total benefits accrued over the study period are valued at $28,192,013 while the net present value of the total costs accrued over the study period are estimated at $5,681,875. Dividing the lifetime benefits by the lifetime costs gives a benefit-cost ratio of 4.96. This means that for every $1 invested into the project, the project is expected to return $4.96 in realized benefits.

Results are presented as Table 7-14 through Table 7-16.

Table 7-14. Sun Valley, CA – GSI TBL Tool Model Results: Stormwater Overview.

Stormwater GSI Practice	Volume Required (CF)	Volume Provided (CF)
Bioretention	167,198	163,854
Wet Pond	8,819,049	8,642,668
Total	**167,198**	**163,854**

Table 7-15. Sun Valley, CA – GSI TBL Tool Model Results: Lifecycle Costs.

Description	Present Value Cost (US Dollars)
Construction Cost	$ 1,474,287
Maintenance Cost	$ 3,292,168
Replacement Cost	$ 1,095,420
Total Lifecycle Cost	**$ 5,861,875**

Table 7-16. Sun Valley, CA – Overview of GSI TBL Tool Benefit Categories.

Benefit Category	Benefit Description	Net Present Value of Benefit
Financial	Avoided Infrastructure Costs	$ 531,495
Financial	Avoided Replacement Costs	$ -
Financial	Energy Savings	$ -
Social	Water Supply	$ 37,783
Social	Air Quality	$ 94,361
Social	Increased Property Values	$ 1,741,207
Social	Heat Stress Reduction	$ -
Social	Recreation	$ 19,464,838
Social	Green Job Creation	$ 60,386
Environmental	Water Quality	$ 4,964,372
Environmental	Carbon	$ 184,820
Environmental	Improvements to Ecosystem Services	$ 1,112,751
Total Net Present Value of Benefits		**$ 28,192,013**

7.5 Comparison of Tools

A comparison of the volume, lifecycle costs, and co-benefits of the tools are shown in Table 7-17 through Table 7-19.

Table 7-17. Sun Valley, CA – Comparison of Stormwater Approach.

Description	Volume Provided (CF) CLASIC Tool	Volume Provided (CF) GSI TBL Tool
Subsurface Infiltration Trench (CLASIC) / Bioretention (GSI TBL Tool)	168,000	163,854
Wet Pond	8,855,000	8,642,668
Volume Provided	**9,023,000**	**8,806,522**

Table 7-18. Sun Valley, CA – Comparison of Lifecycle Costs.

Description	CLASIC Tool (US Dollars)	GSI TBL Tool (US Dollars)
Construction Cost	$ 9,373,848	$ 1,474,287
Maintenance Cost	$ 6,727,583	$ 3,292,168
Replacement Cost	$ 1,095,420	$ 1,095,420
Lifecycle Cost	**$ 17,196,851**	**$ 5,861,875**

Table 7-19. Sun Valley, CA – Comparison of Co-Benefits.

Description	CLASIC Tool (Out of 5 Each or 15 Total)		GSI TBL Tool (US Dollars)	
Social Benefits	1.04	39%	$ 21,398,575	76%
Financial Benefits	1.25	47%	$ 531,495	2%
Environmental Benefits	0.36	14%	$ 6,261,943	22%
Total Benefits	**2.65**	**100%**	**$ 28,192,013**	**100%**

7.6 Key Takeaways

The following are key takeaways from the case study.

1. The tools do not use the same terminology as it relates to design storms, depths, practices, and volumes.
2. Stormwater volume is calculated differently in the tools. In CLASIC, stormwater volume is based on the surface area of the GSI practice and the depth available to store water in the ponding and filter media layers. A void space of 40% is assigned to open graded aggregate/stone and soil storage layers. In the GSI TBL Tool, stormwater volume is based on design depth to capture (feet) and impervious drainage area (square feet), with a factor of 0.98 applied. The GSI TBL Tool consistently provided slightly lower volumes due to the 0.98 factor.
3. The team experienced challenges with making modifications to the pre-populated design criteria in CLASIC. While the tool allowed for customizing the number of practices and drainage area, such modifications often caused the tool to malfunction. It was very challenging to customize the tool to fit the exact design parameters. For this reason, the team modified the design criteria to find a best fit within CLASIC.

4. The tools do not have the same GSI practices available. A subsurface infiltration basin is not one of the options in the GSI TBL tool so a bioretention area was utilized for this comparison.
5. Selecting the importance of co-benefits in the CLASIC tool requires the user to make assumptions based on their knowledge of the project. The CLASIC user manual could benefit from additional instructions, or future updates to the CLASIC tool could run the co-benefits analysis with more targeted user input based on project drivers, project location, or site-specific criteria.
6. Cost data in CLASIC is presented in both the “build scenarios” tab and within the final report. It appears that the costs presented in the build scenarios tab do not account for the number within each design category and/or the discounted cost over the full study period. The costs listed in the advanced tab appear to be per GSI practice, not per unit area or unit volume which is industry standard, and the basis of the GSI TBL Tool costing.
7. Practices that have class options (e.g., rain gardens, sand filters, infiltration trenches detention basin, and wet ponds) were found to range significantly in cost. For example, CLASIC notes that a small rain garden with a footprint of 100 square feet is approximately $122/ square foot, whereas a large rain garden with a footprint of 10,000 square feet is approximately $43/ square foot. This impact is an economy of scale effect.
8. The GSI TBL Tool required a much greater understanding of stormwater management design, benefits quantification, and economics than the CLASIC tool.
9. Both CLASIC and the GSI TBL tool account for vertical side slopes for rain garden and bioretention facilities, instead of sloped side slopes that is traditional for these types of practices. As a result, system volumes and footprints may be underestimated.
10. Based on the CLASIC outputs provided to the user and without additional information or calculations provided in the manual, it was difficult to verify the percent changes in runoff and pollutant loads.
11. The project boundary is not listed on the CLASIC output tab and seemed to disappear from the CLASIC data fields. As this parameter was needed for the GSI TBL Tool, it should be included in the CLASIC outputs.
12. The complexity of this case study was beyond the capabilities of either tool since it relies on a treatment train stormwater management approach where water is routed to a detention pond for storage, then to a wetland for water quality management, and finally to an underground infiltration basin. The project team modeled the wet pond and subsurface infiltration basin only.
13. Both tools capture lifecycle costs for stormwater practices, but do not capture costs associated with other amenities such as new pipe conveyance, pumping stations, and park upgrades.
14. The GSI TBL Tool accounts for benefits associated with stormwater parks (e.g., parks that have stormwater management as a major component of the park upgrade). However, CLASIC does not provide an option for including such features which could have a significant impact on the co-benefits analysis.
15. The CLASIC tool does not allow for infiltration rates more than 5 inches per hour. This is considered a restriction for this project.

16. The CLASIC results of the hydrologic performance are not what was expected, as the results show an increase in annual runoff and a decrease in annual infiltration. The opposite was expected given the large storage volume provided with the wet pond and the addition of infiltration-based practices via the subsurface infiltration trench.
17. The construction cost was set to $0 for the infiltration basin since it was an existing system. In CLASIC, the underground infiltration basin was changed to an existing basin with 8 years left before replacement.

CHAPTER 8

Findings and Conclusions, Recommendations, and Research Gaps

This chapter summarizes the findings and conclusions of the research project, recommendations for tool enhancements, and identified research gaps.

8.1 Findings and Conclusions

Results of the case study comparison are provided in Table 8-1 through Table 8-3.

Table 8-1 provides a comparison of stormwater volume provided in the CLASIC and GSI TBL Tools. Stormwater volume is calculated differently in the tools. In CLASIC, stormwater volume is based on the surface area of the GSI practice and the depth available to store water in the ponding and filter media layers. A void space of 40% is assigned to open graded aggregate/stone and soil storage layers. In the GSI TBL Tool, stormwater volume is based on design depth to capture (feet) and impervious drainage area (square feet), with a factor of 0.98 applied. The GSI TBL Tool consistently provided slightly lower volumes due to the 0.98 factor.

The calculation for stormwater volume in permeable pavement systems accounted for the largest difference between the two tools. This is due to the minimum depth of stone required for pavement stability, which exceeded the design depth to capture in the case studies. In other words, permeable pavement systems can often handle a much larger storm event than the design depths attributed to GSI design.

Table 8-1. Comparison of Stormwater Volume Provided.

Case Study	Case Study Location	GSI Practices	CLASIC Tool Volume Provided (CF)	GSI TBL Tool Volume Provided (CF)
1	Fort Collins, Colorado	Rain Gardens, Permeable Pavement, Sand Filters	312,450	176,354
2	Philadelphia, Pennsylvania	Rain Gardens and Subsurface Trenches	62,400	59,409
3	New Orleans, Louisiana	Rain Gardens and Wet Ponds	10,413,200	10,115,218
4	Phoenix, Arizona	Rain Gardens and Permeable Pavement	23,264	7,930

Case Study	Case Study Location	GSI Practices	CLASIC Tool Volume Provided (CF)	GSI TBL Tool Volume Provided (CF)
5	San Antonio, Texas	Bioswales	9,300	7,791
6	Sun Valley, California	Subsurface Trenches and Wet Ponds	9,023,000	8,806,522

Table 8-2 provides a comparison of lifecycle costs provided in the CLASIC and GSI TBL Tool. Lifecycle costs are calculated as the total of construction costs, maintenance costs, and replacement costs over the lifetime of the asset, expressed as present value. Replacement costs are not automatically calculated for the GSI TBL Tool. For a more direct comparison, replacement costs and timelines were edited to match the outputs from the CLASIC tool.

The calculation for lifecycle cost of the wet ponds accounted for the largest difference between the two tools. This appears to be tied to a model calculation error within the GSI TBL Tool. The unit cost for the wet pond is noted as a cost per volume, $0.67/cubic foot, on the Costs Timeline Tab. However, the lifecycle cost calculation appears to use the footprint instead of the volume in the lifecycle cost calculation. In addition, it is unclear if the wet pond calculation accounts for the cost of excavation for the permanent pool. As a result, case studies with a wet pond resulted in a significantly lower lifecycle cost.

Table 8-2. Comparison of Lifecycle Costs.

Case Study	Case Study Location	GSI Practices	CLASIC Tool Lifecycle Costs (US Dollars)	GSI TBL Tool Lifecycle Costs (US Dollars)
1	Fort Collins, Colorado	Rain Gardens, Permeable Pavement, and Sand Filters	$18,927,029	$17,849,628
2	Philadelphia, Pennsylvania	Rain Gardens and Subsurface Trenches	$3,019,056	$2,033,352
3	New Orleans, Louisiana	Rain Gardens and Wet Ponds	$27,878,751	$8,621,414
4	Phoenix, Arizona	Rain Gardens and Permeable Pavement	$1,050,682	$806,978
5	San Antonio, Texas	Bioswales	$674,868	$422,090

Case Study	Case Study Location	GSI Practices	CLASIC Tool Lifecycle Costs (US Dollars)	GSI TBL Tool Lifecycle Costs (US Dollars)
6	Sun Valley, California	Subsurface Trenches and Wet Ponds	$17,196,851	$5,861,875

Table 8-3 provides a comparison of co-benefit values in the CLASIC and GSI TBL Tool. In CLASIC, co-benefits are calculated as a relative score out of 15 based on user input as to the relevance and importance of various co-benefit categories. In the GSI TBL tool, co-benefits are monetized based on user input on the various co-benefit categories. The GSI TBL tool also provides a benefit-cost ratio in the results tab. The benefit-cost ratio describes the relationship between the relative benefits and costs of a proposed project, calculated as the monetized value of benefits over the lifecycle of the asset divided by lifecycle costs for the project. Projects with a benefit-cost ratio greater than 1.0 represent projects that have benefits that exceed the project costs and deliver a positive value to stakeholders.

While the relative co-benefit score in CLASIC is useful for comparing design alternatives, it has no correlation to the monetized co-benefit values and benefit-cost ratio provided in the GSI TBL Tool.

Table 8-3. Comparison of Co-Benefits.

Case Study	Case Study Location	GSI Practices	CLASIC Tool Co-Benefits Score (Out of 15)	GSI TBL Tool Co-Benefits Value (US Dollars)	GSI TBL Tool Benefit-Cost Ratio
1	Fort Collins, Colorado	Rain Gardens, Permeable Pavement, and Sand Filters	9.59	$6,328,634	0.35 : 1
2	Philadelphia, Pennsylvania	Rain Gardens and Subsurface Trenches	11.67	$2,308,128	1.14 : 1
3	New Orleans, Louisiana	Rain Gardens and Wet Ponds	6.46	$35,003,821	4.06 : 1
4	Phoenix, Arizona	Rain Gardens and Permeable Pavement	12.84	$476,089	0.59 : 1
5	San Antonio, Texas	Bioswales	11.41	$52,004	0.12 : 1

Case Study	Case Study Location	GSI Practices	CLASIC Tool Co-Benefits Score (Out of 15)	GSI TBL Tool Co-Benefits Value (US Dollars)	GSI TBL Tool Benefit-Cost Ratio
6	Sun Valley, California	Subsurface Trenches and Wet Ponds	2.65	$28,192,013	4.80 : 1

8.1.1 CLASIC

CLASIC was found to be better suited for planning projects to compare the outcomes of various practices, scales, performance, and cost. CLASIC allows users to create up to three scenarios of various practices and scales within the same project boundary. This allows users to compare and develop a planning strategy around the right balance of green and gray practices, understand the scale of practices needed to meet various water quality and quantity performance measures, and the associated lifecycle costs for those alternatives.

CLASIC is a user-friendly tool that can be run without much training or support from engineers and economists. The tool is set up with a simple step-by-step process with pre-populated default values and drop-down menu options. The research team was able to develop scenarios within 30 minutes for each case study. For these reasons, CLASIC is recommended for a wider user base at the planning stage of projects.

In CLASIC, the model default is a “do nothing” case. This may be beneficial for users that simply want to compare design alternatives. Due to the limited number of stormwater practices (see Table 1-1), users may find it challenging to accurately capture a true baseline condition (e.g., what stormwater management or water quality measures would be required if the GSI project was not planned).

It was challenging to use CLASIC to model a project that was already designed since stormwater management features are added with pre-defined design features within drop-down menus. Modifications to the number of practices, drainage area captured, and volume provided was limited with the pre-defined design features. While there are ways to break down the overall project area with the use of subunits, it can be challenging to place the stormwater management features in a specific location within the project boundary. For this reason, CLASIC is not recommended for site-specific design.

Below are a few additional key takeaways from the project team’s experience with the CLASIC tool:

1. The team experienced challenges with making modifications to the pre-populated design criteria in CLASIC. While the tool allowed for customizing the number of practices and drainage area, such modifications often caused the tool to malfunction. Additional guidance or checks should be included in the model to avoid such malfunctions.

2. The CLASIC project output report is challenging to print and lacks detail that would be beneficial for users, including a breakdown of cost considerations and supporting calculations for water quality and quantity performance data.
3. It would be helpful to see water quality pollutant load reduction presented as an annual load (pounds/year). It would be helpful to see backup for these calculations in the manual. The project team was surprised by some of the results as noted in the key takeaway sections.
4. The CLASIC tool does not provide the ability to include additional costs for trees, parks, or other improvements that are non-stormwater related, but could potentially have a significant impact on the project outputs.
5. More guidance should be incorporated into the co-benefits analysis and scoring system. It was challenging to identify the level of importance for each benefit category or to understand what types of improvements could be made to improve the score. If the project is not compared to another stormwater alternative within CLASIC, the co-benefit score does not appear to have much significance. It would be helpful to provide recommendations of which co-benefit categories may be important based on project location and drivers.
6. The CLASIC tool is a cloud-based tool that requires a unique password. The team experienced challenges with saving files and sharing this information across users which may be challenging for larger teams.
7. Once the project area is defined within CLASIC, it cannot be updated or modified without starting a new project file. This created some frustration with the project team.
8. For the rain garden and sand filter practices, making changes to the ponding and filter media depth changed the footprint of the GSI practice. The project team expected that the volume would change, but not the footprint. Clarification in the user manual or input screen that the ponding and filter media depth will impact the number of practices required to treat the user entered capture area/depth. The number of technologies and total footprint will then change to meet the volume captured selected by the user.

8.1.2 GSI TBL Tool

The GSI TBL Tool was found to be better suited for projects that were already in design where the stormwater management practices and associated design features have been determined. If this information is not available, the CLASIC tool could be used to generate this required stormwater management design criteria based on selections made with drop-down menus.

The GSI TBL Tool allows users to quantify and monetize various co-benefits associated with GSI which is useful to demonstrate a project’s value with a focus on the triple bottom line. The tool does a great job of taking difficult concepts and calculations and presenting this information in a spreadsheet format.

The GSI TBL Tool requires a more in-depth understanding of both engineering and economics principles to fill in the required fields. The multi-disciplined research team needed approximately 4-8 hours to complete the required fields for each case study analysis. For these reasons, the GSI TBL Tool is recommended for an integrated team of engineers and economists at the design stage of projects.

The GSI TBL Tool requires a deep understanding of the baseline case (e.g., what stormwater management or water quality measures would be required if the GSI project was not planned) since co-benefits are dependent on this information. For example, for communities with combined sewer overflows, the project baseline may include large-scale storage solutions or upgrades to a receiving wastewater treatment plant. For communities with water quality concerns, the project baseline may include large-scale water treatment solutions. For communities with water conservation goals, the baseline may include developing alternative water supply systems.

The co-benefits tabs within the tool present users with a series of questions to accurately calculate both the baseline scenario and the benefits of the GSI approach. The availability of this information may prove challenging to some users.

Below are a few additional key takeaways from the project team's experience with the GSI TBL Tool:

1. The GSI TBL Tool does not provide an analysis of water quality benefits. Water quality is a common project driver that allows capital improvement projects to be prioritized. Without some level of detail provided in the tool, a user cannot understand if projects meet local requirements.
2. The GSI TBL does not provide the ability to include additional costs for parks or other improvements that are non-stormwater related.
3. More background information could be provided to support the project costs, with an option to make modifications to meet current cost trends.
4. The GSI TBL tool project output report is challenging to print. It would be helpful to have a summary chart for sharing information.
5. The case studies all resulted in no energy savings benefits, heat stress credits, or water quality improvement values.

8.1.3 Both Tools

1. The team identified a few calculation errors (see APPENDIX_F) that should be resolved with future model updates.
2. The team recommends updating the CLASIC and GSI TBL tools to make them more complimentary with one another. This could be accomplished by ensuring that the stormwater management practices, design terminologies, and calculations are consistent. In addition, it would be a big improvement if outputs from CLASIC could be automatically uploaded into the GSI TBL tool to streamline the analysis.
3. The team recommends incorporating an environmental equity and social justice lens into both tools.
4. The team recommends updates to the user manuals of both CLASIC and the GSI TBL tool to include comparisons of the practices within the tools.

5. Both tools are run with the assumption that practices are independent of one another and receive a distinct drainage area. The tools could benefit from including options for a treatment train approach, as this is common for stormwater management systems.
6. The tools do not seem to account for other factors that impact GSI performance, such as geotechnical conditions, storm duration and intensity, and how GSI systems are connected (e.g., some systems may be in series).

Table 8-4 provides a tool overview comparison with user experience, inputs, and outputs of each tool.

Table 8-4. WRF Tool Overview Comparison.

Description	CLASIC Tool	GSI TBL Tool
User Experience		
Cloud Based Tool	☑	☒
Excel Based Tool	☒	☑
Includes Regional Cost Adjustment Factors	☑	☑
Ability to Adjust Unit Cost Data	☑	☑
Ability to Compare Multiple Design Scenarios	☑	☒
Time Commitment of 30 Minutes or Less	☑	☒
Tool Inputs		
Applicable for Planning Projects (Minimum Input is Project Location, Stormwater Management Type(s), and Relative Scale of Implementation)	☑	☒
Applicable for Design Projects (Minimum Input is Project Location, Stormwater Management Type(s), and Detailed Stormwater Design Parameters including design footprint, depth, and porosity)	☒	☑

Description	**CLASIC Tool**	**GSI TBL Tool**
Ability to Set and Confirm Compliance with Water Quality Targets	☑	☒
Ability to Adjust Future Land Use and Climate Change Scenarios	☑	☒
Can be Used for Site-Specific Design	☒	☒
Can be Used for Neighborhood and Watershed Scale Analysis	☑	☑
Outputs		
Lifecycle Costs	☑	☑
Relative Scoring System for Co-Benefits (Rated on Scale of 1 – 15)	☑	☒
Monetized Co-Benefits	☒	☑
Quantification of Water Quality Load Reductions	☑	☒
Quantification of Flood Reduction Benefits	☒	☒
Quantification of Environmental Justice and Social Equity Considerations	☒	☒

8.2 Recommendations for Tool Enhancement

Below are some suggestions for potential improvements for the CLASIC and GSI TBL Tool. These suggestions are the result of the team running the Case Studies and comparing the models. Some of these suggestions are more critical if trying to use the tools together for comparison, such as keeping terminology, significant digits, and units consistent for GSI practice inputs.

Comparing the two tools was challenging since the tools use different design parameters, GSI practices, and naming conventions. Table 8-5 provides a comparison of design terminology in the tools.

Table 8-5. Comparison of Design Terminology.

CLASIC	GSI TBL Tool
Average annual runoff	Annual runoff that results in runoff
Annual discount factor	Discount rate
Project boundary	Management area
Depth to capture	Design storm depth
Practices	BMPs
Total captured area	Effective impervious area managed
Total volume captured	Volume capacity by BMP type
Surface area	BMP size
Filter media depth	Depth
Total volume captured	Volume capacity by BMP

As a general recommendation for both tools, both the CLASIC & GSI Co-Benefits tools are reliant upon the design solutions provided by the user, and don't provide their own suggestions to optimize the project. Machine learning processes could run iterative calculations based on project characteristics, design recommendations and resource constraints, and provide solutions unknown to the user that would maximize a project's performance. There could be opportunities to integrate the tools with algorithmic functions or third-party GSI design software add-ons that rely on machine learning and artificial intelligence principles to increase a project's efficiency given a certain set of parameters. There is existing academic literature on the topic; for example, there are studies that use machine learning methods to simulate precipitation runoff, or forecast hydrological responses to urban drainage systems, among other applications.

An additional recommendation for both tools is the addition of disservices related to the projects. This could include construction-related disruptions or a reduction in public parking near businesses.

8.2.1 CLASIC

1. The team recommends providing clear and concise definitions of each design input/parameter with equations for clarity.
2. The co-benefits section should be automatically completed based on project drivers and input rather than having the user select the level of importance. As an alternative, the tool could be modified to provide more information about selecting the importance of each factor. More input should be given about understanding the co-benefits score when there is not a comparison scenario.
3. The team recommends including a hint about keeping file names short and not including symbols within the file name. The project team team had files disappear after spending a significant amount of time developing the case study from incorrect file naming conventions.
4. The team experienced a significant number of errors when first developing the case studies where the team was not able to run the model or view results. It is believed that these errors were caused from modifications to the editable design parameters on the right side of the screen. More research should be invested into the tool functionality.
5. The team recommends allowing GSI practices to be routed in series.
6. The team recommends providing a unit cost table for practices, and classes within practices, to be more transparent about default values. This will allow users a better understanding of when default values do not align with local information.
7. The team recommends summarizing all calculations used in each tool within the user manual. Based on the nature of the tool, users should be able to see how a value is calculated, even if they can't manipulate the input values. Very few calculations are currently provided in the manual.
8. The project team found it challenging to draw in the project area to match the case studies since they didn't have a GIS shapefile. In addition, the project area seemed to disappear from the screen after the linework was drawn. This was a parameter that was used in the GSI TBL Tool, so the team found it frustrating that the project area was not included in the output file. In addition, once the project area is chosen, it can't be edited without starting a new project.
9. CLASIC does not allow for adjustments to subunits after one option is chosen without starting a new project. The project team explored a variety of subunits for each project, and ultimately used a single subunit for each case study as that resulted in the simplest comparison and shortest model run. This is particularly important for using as a planning tool. Users will have a desire to compare multiple areas/scenarios in a time-efficient manner.

10. CLASIC has limits for the design storm depth (10 inches) and seepage rate (5 inches per hour). These limits may be a limiting factor on projects, such as the Sun Valley case study.
11. The team recommends amending the water quality load reductions to include calculation of the loading in terms of pounds per year as well as of percentage reductions. Similarly, the water performance results should be calculated as volume per year as well as percentage reductions.
12. The team recommends providing an input option for additional costs that are not part of the stormwater GSI practice, such as the cost for routing new storm drainage or pump stations.
13. The team recommends updates to the project report summary so that project inputs and outputs are clearly stated and summarized.

14. The team recommends providing a breakdown of cost, hydrology, and water quality values per GSI practice so that the results can provide better insight.
15. The team recommends adding more GSI practices.
16. Water quality pollutant list should be updated to include Chloride.
17. The team recommends including options for separate sewer communities such as avoided potable water costs for irrigation.

8.2.2 GSI TBL Tool

1. The team recommends providing clear and concise definitions of each design input/parameter with equations for clarity.
2. The user manual hints that outputs from CLASIC can be input into the GSI TBL tool. The project team did not find this to be an easy process since there are differences in terminology and project approaches. If the intent is for the tools to be used together, the outputs from CLASIC and the inputs from the GSI TBL tool should be synched in a way that allows for an easier way to input the data.
3. The team recommends including replacement costs as automatic calculations. It was challenging to match the outputs from CLASIC.
4. The team recommends allowing GSI practices to be routed in series.
5. The team recommends providing guidance for acceptable run-on-ratios for various practices as a potential design check.
6. The team recommends allowing for modifications to the design storm per GSI practice instead of per project.
7. The team recommends providing more guidance on design storm percentile as this was not always a known parameter.
8. The team recommends additional research for GSI practice cost as the ranges provided were too varied.
9. The team recommends adding more GSI practices, especially for separate sewer systems.
10. The team recommends providing an input option for additional costs that are not part of the stormwater GSI practice, such as the cost for routing new storm drainage or pump stations.

11. The team recommends providing outputs in the form of pounds removed (or similar unit) in addition to mg/L to account for differences in water quality standards across states.
12. Water quality pollutants should be updated to include TSS, TP, TN, e. Coli, and Chloride.
13. The team recommends determining why the volume provided for permeable pavement varies significantly from the volume provided in CLASIC.
17. The team recommends including options for separate sewer communities such as avoided potable water costs for irrigation.
18. The team recommends including more backup for design calculations. There is concern that some of the benefits may be inflated if the user is not clear on inputs.
19. The team recommends including clarification on the job creation credit and explaining if it accounts for another gray job that is not being used.

8.3 Exclusions/Gaps

The following section outlines exclusions and gaps in the tools.

8.3.1 Flood Reduction

CLASIC and the GSI TBL Tool appear to be set up to model smaller, more frequent storm events typical of GSI design. For projects with a significant amount of storage, the team found it challenging to replicate the storage volume in the tools given the predefined design parameters in CLASIC. In the GSI TBL tool, the design storm and design storm percentage are input on the first screen and then applied to all practices, making it challenging to model sites that were designed with GSI and flood control practices (where the design storms may vary).

Consistent with findings of WRF Project 4852 (Clements, 2021), the project team agrees that flood reduction benefits are very site-specific and would be challenging to model without hydrologic and hydraulic models, topography, building types, and finish floor elevations. Both tools are not set up for such site-specific analysis.

8.3.2 Equity/Environmental Justice

The GSI TBL Tool uses a benefit-cost analysis (BCA) framework to structure the evaluation. BCA is intended to evaluate the economic efficiency and magnitude of a proposed action by summing the effects across individuals. BCA results primarily used for decision-making are the present value of net benefits of the proposed action (e.g., benefits minus costs) and the benefit-cost ratio (BCR) (e.g., benefits divided by the costs). These metrics provide both the magnitude of the benefits and the extent to which they exceed the costs; however, using only aggregated outcomes from BCA does not identify who bears the costs and who receives the benefits and when.

The GSI TBL Tool reporting includes multiple references to equity but doesn’t account for elements of it explicitly outside of job creation. Further, the user manual notes that distributional effects are not considered.

BCA is also constrained in providing a full accounting of all the effects of a proposed action because some impacts may not be possible to monetize or quantify given data and literature availability. Equity and environmental justice are often challenging to isolate in a BCA framework and avoid double-counting with other valued benefits. There may be additional approaches and analytics to supplement the current GSI TBL Tool on this topic, including (a) augmenting the BCA with a distributional impact evaluation, and (b) incorporating additional quantitative key social and environmental justice indicators. Both are discussed briefly below.

8.3.2.1 Distributional Effects

The Office of Management and Budget (OMB) provides guidance on regulatory BCA within OMB Circular A-4, which includes guidance that directs agencies to provide an analysis of the distributional effects of the regulation. Distributional effects as defined by the OMB are how the benefits and costs are distributed across society, disaggregated by characteristics of interest or concern (e.g., income, race, sex, age, geography). If the distributional effects are expected to be significant, OMB specifically calls for a description of "the magnitude, likelihood, and severity of impacts" on groups. With that said, while required, these distributional evaluations are not commonly conducted given lack of specific guidance and data limitations attributing impacts. Analyzing the distributional effects after conducting BCA is important to understanding the significance of a government action or an infrastructure project on social equity, meaning whether the distribution of the benefits and costs is "fair." However, such analyses can be challenging to perform with specificity.

EPA's Guidelines (2014) around regulatory BCA includes content on the approach to take to address distributional effects quantitatively or qualitatively, including metric definitions, sources of data, and analysis methods. It appears that the EPA is the only federal agency to develop guidance for conducting distributional evaluations, but the challenge is that it's limited to health impacts and omits the various non-health impacts of regulation, such as those common in GSI infrastructure, such as Improvements to Ecosystem Services.

This lack of guidance and data is likely a contributing factor to the limited use of distributing factor to the limited use of distributional evaluations in the regulatory setting. However, there may be an opportunity to build in elements of distributional impacts into the TBL GSI Tool at a somewhat less granular level by attributing proportions of certain impacts based on project location and spatial characteristics to specific stakeholder groups. These affected parties could be identified by the tool users, who are likely the most well-positioned given their specific knowledge of the project. Other guidance relating to subgroup population attribution includes Loomis (2011), who suggested three approaches to garner proxies for distribution: (1) information on project financing can help inform the distribution of costs across categories of interest; (2) surveys can be used to estimate how benefits vary across demographic characteristics of interest; and (3) if benefit estimates are calculated using demand or supply functions, then these models can include demographic variables in the statistical analysis to determine distributional effects. These were likely scoping constraints from the TBL GSI Tool engagement but could be considered for future research opportunities.

8.3.2.2 Environmental Justice Indicators

Given the inherent limitations within a BCA framework to identify distributional effects and/or value environmental justice under a broad definition, the development of a set of quantitative indicators, supplementary to the BCA monetized results, would be welcomed. This is like the biophysical impacts often depicted alongside project assessments, such as quantities of carbon and air pollutant sequestered, pollutant loading reductions, volume of stormwater retention or infiltration, etc. These indicators would be complementary to the core function of the BCA outputs and allow for a characterization of equity considerations not currently included in the GSI TBL Tool. There now are a variety of relevant tools and datasets available to leverage for this purpose, which include data such as housing, unemployment, health, air quality, rainfall, climate change risks, local amenities, and other sociodemographic factors, amongst others.

Autocase has developed a free publicly available tool – Building EJ Tool (Autocase, 2022) – which siphons in a diverse set of spatial data for a comprehensive depiction of EJ characteristics. The software is very much intended to be a resource hub and includes an index filled with data, other available EJ tools, relevant organizations, and best-practice guides. The index data dashboard also includes both the project's location characteristics and national averages to compare relative context. The basis for the indicators is primarily aligned with spatial data from the EPA EJScreen (EPA, 2023), a comprehensive set of environmental, socio-economic and, and EJ indexes.

Relevant indicators could be identified in consultation with the affected communities/project teams to inform the selection of indicators applied towards a project as part of a broader set of metrics available.

Equity and environmental justice are important considerations in project planning and more project development considerations/requirements from government departments are elevating these project components. Given the US federal government and academia are the key data and methodological suppliers for economic analysis in the regulatory and infrastructure/capital projects markets, additional research on distributional allocation guidance and other ancillary quantitative metrics to consistently apply in project assessment would be key areas recommended to focus on to support the planning and development community.

APPENDIX A

Triple Bottom Line (TBL) Cost-Benefit Analysis Overview

Appendix A provides an overview of the triple bottom line (TBL) cost-benefit analysis process, credit categories, and outcomes. This chapter is intended for users who are not familiar with performing a TBL cost-benefit analysis.

A.1 TBL Overview

A triple bottom line (TBL) cost-benefit analysis is an accounting system that reviews performance with a focus on financial, social, and environmental outcomes. Conventional cost analyses for stormwater improvements typically include a review of initial capital costs (e.g., planning, design, installation) and lifecycle costs (e.g., operation and maintenance, replacement costs, end of life costs). However, this approach is limited as it does not account for the full range of benefits that can be achieved with GSI and therefore does not provide an accurate basis for reviewing design alternatives. Conversely, a TBL cost-benefit analysis quantifies and monetizes the costs and benefits (or disbenefits, if appropriate) of employing design alternatives with a focus on financial, social, and environmental outcomes. This approach ensures that holistic costs and benefits of each alternative are presented to the decision makers, and ultimately allows for better and more complete decisions to be made with limited resources.

A.2 TBL Process

The TBL process includes identifying the impacts and benefits of various designs, understanding project drivers, and quantifying the outcomes and value. Project drivers for GSI may include combined sewer overflow reduction, water quality improvements, climate resiliency, flood risk reduction, environmental equity/social justice, improved green space/impervious area reduction, urban heat reduction, and water conservation/water scarcity, among others. Project drivers and example key performance indicators are highlighted as Table A-1.

Table A-1. GSI Project Drivers and Key Performance Indicators.

GSI Project Driver	Example Key Performance Indicator(s)	Common Metric(s)
Combined Sewer Overflow Reduction	Volume Managed (Detention and Slow-Release) or Removed (Infiltrated) from Combined Sewer System	Drainage Area Managed and Volume Retained/Treated within GSI Practice
Water Quality Improvements	Reduced Pollutant Loading at Outfalls or at Treatment Plants	Amount of Pollutant Removed from Stormwater Runoff
Climate Resiliency	Green Space Created and Stormwater	Increase in Green Space Area and Volume

GSI Project Driver	Example Key Performance Indicator(s)	Common Metric(s)
	Volume Managed	Retained/Treated within GSI Practice
Flood Risk Reduction	Stormwater Volume Managed	Volume Retained/Treated within GSI Practice
Environmental Equity/Social Justice	Creating value for community	Stormwater Volume Retained/Treated within GSI Practice, Increase in Green Space Area, Amount of Pollutant Removed from Stormwater Runoff, Value of other Social and Environmental Benefits
Improved Green Space/Impervious Area Reduction	Area of Green Space/Reduced Impervious Area	Change in Pervious/Impervious Area
Urban Heat Island Reduction	Area of Green Space/Reduced Impervious Area, Number of New Trees, Area of New Vegetation	Change in Pervious/Impervious Area, Number of New Trees, Area of New Vegetation
Water Conservation/Water Scarcity	Volume Conserved/Infiltrated	Volume Managed, Harvested, or Infiltrated and Reduction on Potable Water Sources

In addition, the following information is required, as a minimum, to run a TBL analysis: project location, climate zone, annual rainfall totals, population, and stormwater management approach (e.g., design storm, area managed, loading ratio, design depth, and system footprint).

A.3 TBL Categories

In a TBL cost-benefit analysis costs and benefits are categorized into financial, social, and environmental categories.

A.3.1 Financial

The financial category of a TBL cost-benefit analysis reviews the economic value created after all capital expenditures, ongoing operations and maintenance, and replacement costs are reviewed. When comparing the use of GSI to traditional gray practices, financial benefits could be achieved through avoided infrastructure and replacement costs, energy savings, or the benefit associated with new, green jobs.

Avoided infrastructure and replacement costs are captured through a detailed assessment of avoided costs with a baseline scenario in which GSI is not part of the solution. Avoided infrastructure costs could be attributable to reduced pumping and treatment, sewer separation, potable water bills, other conventional stormwater management projects, or large-scale storage that is offset from the addition of GSI.

Avoided replacement costs are attributable to the cost for traditional roof or pavement systems as compared to green roofs and permeable pavement systems.

Green job creation benefits are attributable to the ability to create entry-level job opportunities for low income, low-skilled workers to construct and maintain smaller-scale GSI projects as compared to hiring larger companies with a specialized list of skills in tunneling, boring, wastewater treatment plant upgrades, etc.

A.3.2 Social

The social category of a TBL cost-benefit analysis reviews the social benefits created by the incorporation of vegetation and green space. Social benefits could be achieved through improvements to public health, property uplift, recreational value, educational value, heat island reduction, and avoided flood damage.

A.3.3 Environmental

The environmental category of a TBL cost-benefit analysis reviews the environmental benefits created by the incorporation of vegetation and green space. Environmental credits include carbon emission sequestration, air pollution sequestration, water quality, air quality, and species diversity.

A.4 TBL Outcomes

TBL outcomes often include lifecycle costs and either scores or monetized values for financial, social, and environmental benefits. This information can be used to evaluate a variety of stormwater management approaches and ensures that holistic costs and benefits of each alternative are presented to the decision makers. This allows for better and more complete decisions to be made with limited resources.

APPENDIX B

Detailed Review of CLASIC Tool

Appendix B provides a detailed overview of WRF's CLASIC Tool with tool inputs, outputs, and steps.

B.1 CLASIC Tool Overview

The Water Research Foundation released the Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs tool (CLASIC) in April 2021. This project was funded by the EPA's Office of Research and Development through a grant opportunity "National Priorities: Lifecycle Costs of Water Infrastructure Alternatives". Stormwater experts from U.S. universities, engineering firms, and nonprofits contributed to the tool's development.

The CLASIC tool is a cloud-based web screening tool that can be used to assess life-cycle costs, stormwater performance, and social and environmental benefits of GSI practices at the community, watershed, and neighborhood scales. A nominal level of stormwater and economic expertise is required to run and understand the tool. The expected users are consultants, academics, and managers and operators of combined and separate stormwater systems. The tool is accessible after users register for a free account.

CLASIC can be used to compare and assess the effectiveness of different stormwater strategies and to evaluate runoff volume reduction, water quality, social and environmental benefits, and lifecycle costs. This tool is especially useful for determining planning level costs and for comparing various stormwater alternatives when detailed design information is not available. The steps of the CLASIC tool include defining the study area, selecting climate data, defining model defaults, building scenarios, setting the importance of co-benefits, setting targets, and finally running the tool and viewing outputs.

The tool has a geographical information system (GIS) interface and interacts with national databases to upload data for the planning area. This includes specific factors such as percent impervious area, soil types, land slopes. Information can also be accessed from sources like the U.S. Census, National Land Cover Database, and EPA BASINS Model to provide a baseline for the project area's climatological and hydrological conditions. There is also an option to incorporate international-standard climate change scenarios through a Multivariate Adaptive Constructed Analogs (MACA) method. Inputs into the tool include the project location, stormwater approach, and scale of application (such as small, medium, or large).

B.2 CLASIC Tool Outputs

The three main outputs from the CLASIC tool are lifecycle costs, co-benefits, and performance. The lifecycle cost provides feasibility-level municipal budget estimates over time for a variety of GSI construction and maintenance costs. A multi-criteria decision analysis (MCDA) informs the co-benefits analysis by providing a quantitative comparison across various scenarios.

Performance scenarios are estimated through hydrologic (peak runoff and volume reduction) and pollutant load reduction metrics. It is noted that CLASIC is not meant for site-specific design of stormwater infrastructure, for comparison of spatial distribution within a project area, or to optimize a design.

B.3 CLASIC Tool Steps

CLASIC includes icons on the left side of the screen to guide the user through the steps of the CLASIC Tool. A detailed user guide for the CLASIC Tool can be found on the tool's website (WRF, 2023). A summary of each step is provided below.

Step #1: Define Planning Study Area

To start, users are instructed to create, import, or select an existing project from the saved files. Once a file name is assigned, the user is instructed to delineate the planning study area with the use of a drawing tool or shape file, if available. The planning study delineates the outer boundary of the area that will be evaluated.

The next step is to identify the subunits. The analysis can be conducted with a single subunit or with several subunits, such as US census block, block group, and tracts. US census tracts are the largest subunit selection, and a single subunit is the smallest. The user guide notes that increasing the number of subunits can allow for more control over where practices are applied but can increase run time for the tool.

Step #2: Select Climate Data

The next step is to select climate data for the study area. The climate data tab provides drop down menus to select local precipitation and evaporation stations. The analysis period is automatically adjusted based on the climate data but could be adjusted by the user if desired.

Step #3: Define Default Parameters

The model defaults tab allows more experienced users to review and modify default parameters within the model. Drop-down menus are available for modifications to the subunits, water quality inputs, overland flow characteristics, infiltration, GSI practice effluent, and lifecycle cost data. If subunits are used, the GSI practice drainage area and relevant design information is provided per subunit. It is noted that the default parameters in the program are sufficient to run the tool without modifications.

Step #4: Build Scenarios

The build scenarios tab allows the user to develop a baseline and new scenarios with a range of practices. The baseline scenario represents the current system, and the default is a "do nothing scenario" without practices added. The baseline scenario could also be adjusted to include practices to compare what steps could be taken to meet the same objectives if the GSI project is not implemented.

CLASIC includes drop-down menus for the following practices: rain garden, sand filter, infiltration trench, detention basin, wet pond, stormwater harvesting, storage vault, permeable pavement, disconnection, and green roofs. Each GSI practice includes pre-populated design parameters that can be modified by the user to match proposed conditions, including stormwater management goals, management area, and scale of implementation. The model allows for modifications to costs and future land use and climate scenarios.

Step #5: Co-Benefits Analysis

The co-benefits analysis tab requires input on the importance of a variety of economic, social, and environmental factors. Users are instructed to identify which benefits are applicable and to rate their impact using a scale of 1 to 4 as follows:

1 = Not Important/Not applicable

2 = Somewhat Important

3 = Medium Importance

4 = Very Important

The user manual provides methodologies for estimation of co-benefits. Table B-1 is a summary of each co-benefit category and CLASIC parameter used for estimation.

Table B-1. CLASIC Co-Benefits Analysis Overview.

Co-Benefit Category	Co-Benefit	CLASIC Parameter Used for Estimation
Financial	Increased Property Values	Reduction in Impervious Cover / Increase in Green Space
Financial	Reduced Costs from Illness	Increase in Plants, Trees, and Green Roofs
Financial	Avoided Costs from Combined Sewer Treatment	Combined Sewer Systems Only; Runoff Volume Reduction
Financial	Reduced or Mitigated Impacts from Nuisance Floods	Runoff Volume Reduction
Financial	Enhanced Building Energy Efficiency	Area of Green Roof
Financial	Avoided Water Treatment	Volume of Stormwater Harvested
Financial	Improvements to Employment Opportunities	Maintenance Cost
Social	Health Benefits from Improvements to Air Quality	Increase in Plants, Trees, and Green Roofs

Co-Benefit Category	Co-Benefit	CLASIC Parameter Used for Estimation
Social	Mental Health Improvements	Reduction in Impervious Cover / Increase in Green Space
Social	Improvements to Thermal Health	Reduction in Impervious Cover / Increase in Green Space
Social	Increased Water Supply from Harvested Stormwater	Volume of Stormwater Harvested
Social	Increased Public Awareness of Stormwater and Water Systems	Number of Stormwater Practices
Social	Potential Avoided Social Strain Associated with Nuisance Flooding	Runoff Volume Reduction
Environmental	Improvements to Ecosystem Services	Diversity of Vegetation
Environmental	Increased Groundwater Flow	Runoff Volume Infiltrated
Environmental	Carbon Sequestration	Increase in Plants, Trees, and Green Roofs

Step #6: Set Targets
The target tab can be used to identify specific performance targets such as percent pollutant reduction, runoff reduction, total cost, and annual average cost. The tool will notify the user when scenarios do not meet those targets, but they are not required to run the tool.

Step #7: Review Results
Results in CLASIC include a lifecycle cost analysis, co-benefit analysis, hydrologic performance (e.g., changes in runoff volume, infiltrated volume, and evaporated volume), and water quality performance. Users can select up to three design alternatives to review at one time.

APPENDIX C

Detailed Review of GSI TBL Tool

Appendix B provides a detailed overview of WRF's CLASIC Tool with tool inputs, outputs, and steps.

C.1 GSI TBL Tool Overview

The Economic Framework and Tools for Quantifying and Monetizing Triple Bottom Line Benefits of Green Stormwater Infrastructure (GSI TBL tool) was completed by WRF in 2021. The GSI TBL tool is an excel-based tool that supports the quantification and monetization of environmental, social, and financial benefits of GSI at the community, watershed, or neighborhood scale.

The GSI TBL tool is accessible after the user registers for a free Water Research Foundation Public Plus account. This tool requires expertise and familiarity with economics and GSI implementation and planning. It may be more appropriate for projects with a multi-disciplined team, including an engineer and economist.

Inputs to the GSI TBL tool include project location, BMP (referred to as GSI practice in CLASIC and throughout the report), and associated design parameters. The tool leads users through a TBL-based benefit/cost analysis, from establishing a baseline to applying appropriate economic valuation methods and comparing benefits and costs over time.

C.2 GSI TBL Tool Outputs

Users are guided through a series of steps within the GSI TBL Tool to establish a scenario to model, define a baseline, and identify benefits within a triple bottom line framework. The tool estimates lifecycle cost and provides a summary of monetized community-level co-benefits.

C.3 GSI TBL Tool Steps

The GSI TBL tool includes a series of tabs within the Excel document, including key inputs, green stormwater infrastructure (GSI) scenario, costs timeline, and a range of co-benefits to explore. A detailed user guide for the GSI TBL Tool can be found on the WRF’s website (Clements, 2021). A summary of each step is provided below.

Step #1: Establish the Baseline

The baseline scenario is used to compare what steps could be taken to meet the same objectives if the GSI project is not implemented. For communities within a combined sewer system, the baseline scenario may be the addition of large tunnels in lieu of GSI. Establishing a baseline likely requires hydrologic and hydraulic modeling and planning efforts.

Step #2: Define Key Inputs

Key inputs include annual rainfall that results in runoff, design storm expressed as a percentile, design storm depth, management area, management area population, and climate zone.

Annual rainfall that results in runoff was taken from the outputs of CLASIC, but can also be calculated using the US Environmental Protection Agency National Stormwater Calculator. Annual rainfall that results in runoff is a function of land cover, underlying soil conditions, and annual precipitation. Design storm percentile and design storm depth are based on local design standards. Design storm percentile is typically presented in the range of 80 to 90 percentile and design storm depths are typically in the 0.5-to-2-inch range for GSI, and up to 10 inches for systems that provide added flood management. The management area represents the drainage area that will be managed within the GSI practices. This information was set to match the design inputs for the CLASIC tool. Management area population was calculated by multiplying the management area by the city's population density which can be determined from the US Census Bureau.

Step #3: Define GSI Scenario

Design specifications for the GSI practice are entered in the GSI Scenario tab. The first section lists the GSI practices included in the tool, and the equivalent GSI practice in the CLASIC tool (if there is such a match). A comparison of available practices in each tool is presented as Table C-1.

The user must enter either the effective impervious acres managed by the GSI practice, or number of practices for tree planting and rainwater harvesting. The tool then calculates each GSI practice's volume capacity, size, and annual runoff volume.

The second section includes design specifications for each GSI practice including depth, ponding depth, porosity, volume capacity, average size of the GSI practice, and run-on ratio (e.g., impervious area managed as a ratio to the system footprint area). While the GSI TBL Tool provides default values for the design specifications, the user can override these quantities to better match their project data.

Table C-1. Comparison of Practices in CLASIC and GSI TBL Tool.

GSI TBL Tool GSI Practice	CLASIC GSI Practice
Rain Gardens	Rain Garden
Bioretention Facilities	Infiltration Trench
Green Roofs	Green Roof
Tree Planting / Street Trees	Not Included in CLASIC
Permeable Pavement	Permeable Pavement
Cisterns – Rainwater Harvesting	Stormwater Harvesting
Rain Barrels – Rainwater Harvesting	Stormwater Harvesting

GSI TBL Tool GSI Practice	CLASIC GSI Practice
Constructed Wetland	Not Included in CLASIC
Wet Ponds	Wet Pond
Biofiltration / Grass or Vegetated Swale	Not Included in CLASIC
Not Included in GSI TBL Tool	Sand Filter
Not Included in GSI TBL Tool	Detention Basin
Not Included in GSI TBL Tool	Storage Vault
Not Included in GSI TBL Tool	Disconnection

Step #4: Define Costs Timeline

The Costs Timeline tab calculates the cash outflows related to the project. The first section provides unit costs for the GSI practices included in the GSI TBL Tool. The capital costs are provided as a cost per unit basis (e.g., cost per square foot, cost per cubic foot, or cost per gallon). This section also includes annual maintenance costs for the various GSI practices, expressed as percentages of capital cost. These costs are meant to be a reference for the user, who has the option to update these costs if they have more accurate costing data.

The second section is a schedule that models overall project costs. The user has the option to input their own capital costs or annual maintenance costs. If left empty, the tool will model its own cost schedule based on the construction year and construction period entered by the user, as well as the GSI practice unit costs. The user can also include projected replacement costs in their respective year. However, replacement costs are not estimated by the tool.

Step #5: Review Benefits and Costs

The GSI TBL Tool monetizes benefits across three benefit categories: financial, social, and environmental. Table C-2 provides an overview of each tool and the relevant GSI practices in which those benefits may be appropriate.

Table C-2. Review of Benefit Categories in GSI TBL Tool.

Benefit Category	Benefit Description	Relevant GSI Practice
Financial	Avoided Infrastructure Costs	All GSI Practices
Financial	Avoided Replacement Costs	Green Roofs and Permeable Pavement
Financial	Energy Savings	Trees and Green Roofs (Building

Benefit Category	Benefit Description	Relevant GSI Practice
		Energy Savings); All GSI Practices (Utility Energy Savings)
Social	Water Supply Benefits	Rainwater Harvesting Systems, Bioretention, Rain Gardens, Wet Ponds, and Wetlands
Social	Improvements to Air Quality	Trees, Green Roofs, Rain Gardens, Bioretention, and Wetlands
Social	Increased Property Values	Trees, Bioretention, Rain Gardens, Green Roofs, Wet Ponds, and Wetlands
Social	Heat Stress Reduction	Trees, Rain Gardens, Bioretention, Wetlands, and Green Roofs
Social	Improved Recreation	Trees, Rain Gardens, Bioretention, Wetlands, Wet Ponds, and Green Roofs
Social	Green Job Creation	All GSI Practices
Environmental	Water Quality Improvements	All GSI Practices
Environmental	Carbon Emissions Reduction	Trees, Green Roofs, Bioretention, Rain Gardens, and Wetlands
Environmental	Improvements to Ecosystem Services	Trees, Green Roofs, Bioretention, Rain Gardens, and Wetlands

Each are described in more detail below.

(1) Financial Benefit: Avoided Infrastructure Costs

This tab allows the user to select between two options to calculate avoided infrastructure costs. In the first option, users can manually enter avoided capital costs and avoided annual Operation and Maintenance (O&M) costs. The second option allows the user to employ various avoided cost calculators. If the project avoids the need for large-scale combined sewer overflow (CSO) reduction projects, such as deep tunnels or sewer separation projects, or any other stormwater management project or stormwater pumping and treatment costs, then the user can toggle that individual calculator. The user can enter information on the avoided project, such as the volume of a storage facility or the acreage of a sewer separation study area. The calculators will then calculate the value of the avoided capital and O&M costs.

Avoided infrastructure and replacement costs are captured through a detailed assessment of avoided costs with a baseline scenario in which GSI is not part of the solution. Avoided infrastructure costs could be attributable to reduced pumping and treatment, sewer separation, potable water bills, other conventional stormwater management projects, or large-scale storage that is offset from the addition of GSI.

Avoided replacement costs are attributable to the cost for traditional roof or pavement systems as compared to green roofs and permeable pavement systems.

Green job creation benefits are attributable to the ability to create entry-level job opportunities for low income, low-skilled workers to construct and maintain smaller-scale GSI projects as compared to hiring larger companies with a specialized list of skills in tunneling, boring, wastewater treatment plant upgrades, etc.

(2) Financial Benefit: Avoided Replacement Costs

This tab allows the user to calculate avoided replacement and maintenance costs when using green roofs and permeable pavement materials in lieu of traditional roofing and paving materials. The tool provides default values for maintenance costs, replacement costs, and asset life, which can be modified if more accurate information is available.

(3) Financial Benefit: Energy Savings

This tab calculates energy savings through four potential avenues: addition of trees, implementation of green roofs, stormwater pumping and treatment, and potable water supply offsets. However, the energy savings benefit is only calculated from the energy savings created by the addition of trees and green roofs that the user added in the GSI Scenario Tab. The energy savings calculated from stormwater pumping and treatment and potable water supply offsets flows into the Air Quality and Carbon Reduction benefits calculation.

Trees

The user must enter the project’s state, and the tool will pull the average cost of electricity and natural gas. The user also has the option to enter manual electricity and natural gas costs. The tool calculates energy savings from trees by multiplying the average energy cost by the average annual energy savings per tree based on the previously selected US Forest Service Stratum climate zone. The number of trees must be input by the user on the GSI Scenario Tab.

Green Roofs

The user must select the nearest reference city to the project city from a dropdown menu and can update the default green roof parameters. The tool calculates energy costs, which the user can manually override, and energy savings. The tool multiplies these values to calculate the energy savings from green roofs.

Stormwater Pumping and Treatment

The energy savings calculated in this section flow into the Air Quality and Carbon Reduction benefit calculations. The user selects between manually entering average wastewater pumping and treatment energy intensity, or using the built-in calculator, which pulls average treatment energy intensity based on average plant flow. The tool multiplies the energy intensity value by the volume of stormwater retained to calculate energy savings from stormwater pumping and treatment.

Potable Water Supply Offsets

The energy savings calculated in this section flow into the Air Quality and Carbon Reduction benefit calculations. The tool has default values for average surface water and groundwater energy intensity, which the user can override. The tool uses these values and the volume of rainwater harvesting from the GSI practices to calculate energy savings from potable water supply offsets.

(4) Social Benefit: Water Supply

This tab calculates water supply benefits as the sum of the value of water harvesting and the value of water recharge. In the first section, the tool calculates potable offsets from rain barrels and cisterns. The user enters the value of potable water supply offsets, using the reference table, provided by the tool, containing the retail rate, and avoided cost value of potable water. In the second section, the user selects the project's state from a dropdown menu and enters the value of potable water supply offsets. The tool provides a reference table for this value, like the reference table in the first section.

(5) Social Benefit: Air Quality

This tab calculates air emission savings through three avenues: energy use reduction, addition of trees, and addition of other vegetation. For the energy use reduction section, the user must select the project's eGRID region and AVERT region from the dropdown menus. The tab has a map of each regional breakdown to assist the user. Similarly, the user must select the project's state from a dropdown menu for the addition of trees section. The tool then pulls the annual energy savings calculated in the Energy Savings benefit, as well as the number of trees and area of other vegetation added by the user in the GSI Scenario Tab. The tool automatically pulls reduced air pollutant emissions values based on the selected regions, and air pollutant removal values based on the added trees and vegetation added by the user in the GSI Scenario Tab. it then multiplies these quantities with built-in social costs to monetize this benefit.

(6) Social Benefit: Property Values

This tab lets the user toggle between two methods of estimating baseline property values. The first method allows the user to manually enter the number of single-family and multi-family properties in the management area, and their respective aggregate values. The second method directs the user towards the US Census to pull the count and aggregate value of units by structure type for the project's location and calculates a ratio between the management area and the project city's area in the Census. The tool then calculates a total average of the property value increases based on the inputted GSI practices. The user then selects the percentages of total properties affected by these GSI improvements, and any subset of properties to exclude.

(7) Social Benefit: Heat Stress Reduction

This tab calculates reduced heat stress for the implementation of permeable pavement. The user must enter the closest U.S. municipality to the project location from a dropdown menu, and then toggle between two options for determining the quantity of permeable pavement installed. The first option applies the GSI benefit across the management area, whereas the second option applies the GSI benefit to a concentrated area. The tool then pulls the temperature reduction and the change in days with a temperature above the minimum mortality temperature. The tool calculates the number of future reductions in heat-related deaths, emergency room visits and hospitalizations, and monetizes these using social costs.

(8) Social Benefit: Recreation

This tab calculates recreation benefits through four green space types: pocket parks (e.g., small street or neighborhood-scale parks), stormwater parks (e.g., parks that have stormwater management as a major component of the park upgrade), wetland area recreation, and general neighborhood greening. The user indicates whether the selected GSI practices include the creation or enhancement of green space. For each type of green space, the user enters data such as the additional acreage, the number of residents within a 1-mile radius, and the percentage of the area that will support recreational activity. With these inputs, the tool calculates the expected annual visitors to the different green space types. The user then answers questions relating to pocket parks and stormwater parks (e.g., parks that have stormwater management as a major component of the park upgrade) with dropdown menus, such as the types of offered recreational activities, the availability of similar opportunities nearby, and the accessibility and quality of the park. With this data, the tool calculates the recreational value per trip for the various green spaces.

(9) Social Benefit: Green Jobs

This tab calculates the number of construction and maintenance jobs created by the GSI project. The number of construction jobs is estimated based on the project's construction job-years and the number of jobs created per $1 million of capital spending, which can be edited from its default value. Annual maintenance jobs are automatically estimated based on certain selected GSI practices. The user then selects the percentage of construction and maintenance jobs filled by unemployed or underemployed persons. The tool includes two valuation methods to monetize this benefit: the reservation wage approach or the avoided social cost approach. The reservation wage is the lowest wage an individual will accept, whereas the avoided social cost refers to the cost that (local, state, and federal) governments would incur to support an unemployed individual. The user's choice will depend on which perspective they are focusing on. If they want to highlight the additional workers to a community, they should choose the reservation wage approach. If they are interested in the benefit accrued by the larger society, they should choose the avoided social cost approach.

(10) Environmental Benefit: Water Quality

This tab asks the user to specify the baseline level of water quality and expected improvements. There are also togglable options for the user to specify if the water quality change occurs in an estuary, affects only local freshwater bodies, and if the affected water body supports recreation. The user must also select the project's state, input the median household income in 2010 USD, and estimate the number of households in the management area.

(11) Environmental Benefit: Carbon

This tab calculates carbon reduction through four avenues: reduced energy use, addition of trees, implementation of green roofs, and implementation of rain gardens, bioretention facilities and wetlands. The tool prepopulates the energy savings calculated in the earlier benefit. The user enters the project's eGRID region and can update the CO2e emission factor and social cost of carbon if desired. The tool calculates the annual avoided CO2e emissions using the selected emission factor and monetizes it using the social cost of carbon. Based on user input on the GSI Scenario Tab, the tool populates the number of trees and the area of green roofs, rain gardens, bioretention facilities and wetlands, and monetizes the carbon reduction benefit in a similar fashion.

(12) Environmental Benefit: Improvements to Ecosystem Services

This tab calculates the Improvements to Ecosystem Services benefit by estimating the area of habitat created by each vegetated GSI practice. The user can edit the default values provided for each GSI practice. These areas are then multiplied by social costs to estimate the total ecosystem service benefit.

APPENDIX D

Available Tools to Support Design and Valuation of GSI

Table D-1 of Appendix D provides an overview of available tools to support the design and valuation of green stormwater infrastructure (GSI). Each tool is described in more detail in the following section. Appendix E provides a GSI performance and valuation tool matrix.

Table D-1. Overview of Available Tools to Support Design and Valuation of GSI.

Report Section	Publishing Organization(s)	Name / Link to Tool	Tool Function(s)
D.1	Autocase	Building EJ Tool[1]	Environmental Justice Screening and Mapping Tool
D.2	Center for Neighborhood Technology	Green Values Stormwater Management Calculator[2]	BMP Performance and Stormwater Valuation
D.3	Earth Economics	Green Infrastructure Valuation Tool[3]	Stormwater Valuation
D.4	i-Tree	i-Tree Hydro Model[4]	BMP Performance
D.5	Minnesota Pollution Control Agency	Minimal Impact Design Standards (MIDS) Best Management Practice (BMP) Calculator[5]	BMP Performance
D.6	US Environmental Protection Agency	Best Management Practice Accounting and Tracking Tool (BATT)[6]	BMP Performance
D.7	US Environmental	EJScreen[7]	Environmental Justice Screening and

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[1] https://www.ejtoolkit.com/
[2] https://greenvalues.cnt.org/
[3] https://giexchange.org/green-infrastructure-co-benefits-valuation-tool/
[4] https://www.itreetools.org/tools/hydro
[5] https://stormwater.pca.state.mn.us/index.php/MIDS_calculator
[6] https://www.epa.gov/npdes-permits/stormwater-tools-new-england
[7] https://ejscreen.epa.gov/mapper/

Report Section	Publishing Organization(s)	Name / Link to Tool	Tool Function(s)
	Protection Agency		Mapping Tool
D.8	US Environmental Protection Agency	Green Infrastructure Flexible Model (GIFMod)[8]	BMP Performance
D.9	US Environmental Protection Agency	Green Infrastructure Wizard (GIWiz)[9]	Access to EPA Tools and Resources
D.10	US Environmental Protection Agency	Integrated Decision Support Tool (i-DST)[10]	BMP Performance and Stormwater Valuation
D.11	US Environmental Protection Agency	National Stormwater Calculator[11]	BMP Performance
D.12	US Environmental Protection Agency	Storm Water Management Model (SWMM)[12]	BMP Performance
D.13	US Environmental Protection Agency	Visualizing Ecosystem Land Management Assessments (VELMA) Model[13]	BMP Performance
D.14	US Environmental Protection Agency	Watershed Management Optimization Support Tool (WMOST)[14]	BMP Performance
D.15	Virginia Department of Environmental Quality	Virginia Runoff Reduction Method (VRRM)[15]	BMP Performance

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[8] https://gifmod.com/download-gifmod-installation-file/
[9] Green Infrastructure Wizard | US EPA
[10] https://idst.mines.edu/
[11] https://swcweb.epa.gov/stormwatercalculator/
[12] https://www.epa.gov/water-research/storm-water-management-model-swmm
[13] https://www.epa.gov/water-research/visualizing-ecosystem-land-management-assessments-velma-model
[14] https://www.epa.gov/ceam/wmost
[15] Virginia Stormwater BMP Clearinghouse (vt.edu)

Report Section	Publishing Organization(s)	Name / Link to Tool	Tool Function(s)
D.16	Water Research Foundation	Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs (CLASIC)[16]	Stormwater Valuation
D.17	Water Research Foundation	Economic Framework and Tools for Quantifying and Monetizing the Triple Bottom Line Benefits of Green Stormwater Infrastructure (GSI TBL Tool)[17]	Stormwater Valuation
D.18	Wisconsin Department of Natural Resources	RECARGA Model[18]	BMP Performance

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[16] https://clasic.erams.com/

[17] https://www.waterrf.org/research/projects/economic-framework-and-tools-quantifying-and-monetizing-triple-bottom-line

[18] https://dnr.wisconsin.gov/topic/Stormwater/standards/recarga.html

D.1 Autocase Building Environmental Justice (EJ) Tool

The Building EJ Tool was developed by Autocase to provide the data, resources, and framework to identify pressing issues related to environmental justice. The tool provides a data dashboard with socioeconomic, environmental, climate change, amenity, and demographic data.

This free planning tool has been developed for design teams and community development advocates to be used on building projects. The toolkit provides the data, resources, and framework to identify pressing issues and document project planning process to account for more equitable design. The resource hub is an index filled with Environmental Justice Data, Tools, Organizations and Guides so users can easily find them all in one place. The tool connects local experts through a public-facing directory of EJ practitioners & community advocates for design teams to find and cultivate beneficial relationships with their projects. It also allows connections with specific projects with a public-facing dashboard for local community advocates, EJ practitioners, and community-based organizations to gain transparency into projects and actively connect with design teams.

D.2 Center for Neighborhood Technology Green Values Stormwater Management Calculator

The Center for Neighborhood Technology developed an online application to assess GSI performance and stormwater valuation. The Green Values Stormwater Management Calculator compares the performance, costs, and financial benefits for a range of GSI practices. The calculator includes templates for a variety of scales, from single lots to neighborhood improvements, which allows the tool to be accessible to a wide audience. A low level of stormwater and economic expertise is required for this calculator. It is accessible through the Center for Neighborhood Technology’s website.

The tool includes input tabs for general site information (e.g., lot area and land cover), zip code (to download relevant rainfall data), volume capacity capture goal (with recommendation for national averages), and proposed stormwater management improvements. Each stormwater management improvement is provided as a drop-down menu with a series of questions related to the quantity or percentage of area captured within the GSI practice. Benefits are presented as financial benefits only. Environmental and social benefits are discussed in a companion Green Values Strategy Guide Manual.

D.3 Earth Economics Green Infrastructure Valuation Tool

The Green Infrastructure Co-Benefits Valuation Tool is an Excel-based tool that provides framework, methods, and values to support rapid screening-level analysis of the costs and benefits associated with GSI investments. A medium level of stormwater and economic expertise is required for this tool. The Excel tool and guidebook can be downloaded from the Green Infrastructure Leadership Exchange website.

The tool provides drop-down menus for a range of GSI practices with default regional values and design assumptions to provide a quick result with minor required inputs. The tool includes inputs for project location (e.g., select state) and GSI practice sizing and contributing drainage area. Other inputs include the number of homes adjacent to the planned improvement and accounting of existing and proposed trees. The tool includes rain gardens and bioswales, pervious pavement, bioretention ponds, urban forest, wetlands, and green roofs.

D.4 i-Tree Hydro Model

i-Tree is an organization that provides free tools using USDA Forest Service data and current, peer-reviewed tree benefits estimation science. The i-Tree Hydro Model is a flexible tool for users interested in comparative analyses of different land cover scenarios and their hydrological impacts at various scales. i-Tree Hydro is a stand-alone desktop application designed to simulate the effects of changes in urban tree cover and impervious surfaces on the hydrological cycle, including streamflow and water quality, for watershed and non-watershed areas. A high level of stormwater and economic expertise is required for this model. The model and associated guidebook can be downloaded from i-Tree's website.

Inputs to the model include location, precipitation data, land cover characteristics, underlying soil properties, canopy interception, rate of evaporation and transpiration, and storage.

D.5 Minnesota Pollution Control Agency Minimal Impact Design Standards Best Management Practice (MIDS BMP) Calculator

The Minnesota Pollution Control Agency developed the MIDS BMP Calculator to evaluate GSI performance. The MIDS BMP calculator is a tool used to determine stormwater runoff volume and pollutant reduction capabilities of various stormwater management typologies. This tool is applicable for communities in Minnesota to document compliance with the Minnesota Minimal Impact Design Standards. A high level of stormwater and economic expertise is required for this calculator. The tool and associated guidebook can be downloaded from MPCA's website.

The tool includes the following stormwater management typologies: green roof, bioretention basin, infiltration basin/underground infiltration, permeable pavement, tree trench system/box, swales, rainwater reuse/cistern, sand filter, constructed stormwater pond, constructed wetland, or other user-defined practices.

D.6 US EPA Best Management Practice Accounting and Tracking (BATT) Tool

Developed by the US EPA, BATT is an Excel-based BMP performance calculator that provides accounting, tracking, and reporting for nutrient load reduction over time. The BATT tool is used to track net increases or decreases in nutrient load reductions associated with changes in land use and the implementation of stormwater management practices. A medium level of stormwater and economic expertise is required for this tool. BATT and the associated guidebook can be downloaded from the EPA's website under Stormwater BMP Pollutant Removal Tools and Information.

BATT is applicable for communities within US EPA Region 1 (Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont) to document compliance with MS4 permit requirements and/or TMDL nutrient load reduction requirements. Nutrient loading rates for phosphorus, nitrogen, and total suspended solids are calculated based on user inputs for land use and underlying soil conditions. Project location, stormwater approach, and associated design parameters are required for BATT.

The tool includes options for structural, non-structural, and land use conversions to meet nutrient load reductions. Structural practices include biofiltration, enhanced biofiltration, extended dry detention pond, grass swale, infiltration basin, infiltration trench, porous pavement, sand filter, and wet pond/created wetland. Non-structural practices include catch basin cleaning, enhanced street sweeping program, impervious area disconnection, fertilizer controls, and organic waste/leaf litter collection programs.

D.7 US EPA EJScreen

EJScreen is a US EPA publicly available environmental justice mapping and screening tool that provides a nationally consistent dataset and approach for combining environmental and demographic socioeconomic indicators. EJ Screen includes twelve environmental indicators, seven socioeconomic indicators, twelve EJ indexes, and twelve supplemental indexes. The tool includes color coded mapping, the ability to generate a standard report for a selected area, and a comparison of how that selected area compares with the state, EPA region, or nation. The screening tool can be found through EPA's website.

D.8 US EPA Green Infrastructure Flexible Model (GIFMod)

US EPA Green Infrastructure Flexible Model is a computer program that can be used to evaluate the performance of GI practices. Modeling of GI performance in GIFMod can be done in three levels, including hydraulics, particle transport, and constituent fate and transport. The tool and guidebook are available on EPA's website.

D.9 US EPA Green Infrastructure Wizard (GIWiz)

US EPA Green Infrastructure Wizard is an interactive web application that connects communities to EPA GI tools and resources from a range of categories including general information, community specific projects, and ideas for designing and assessing projects. The tool and guidebook are available on EPA's website.

D.10 US EPA Integrated Decision Support Tool (i-DST)

US EPA Integrated Decision Support Tool is a life-cycle cost assessment and performance tool to evaluate options for improving stormwater runoff management and enhancing co-benefits for GI design. The tool and guidebook are available on EPA's website.

D.11 US EPA National Stormwater Calculator

US EPA National Stormwater Calculator is a software application to assess GSI performance. It is a web-based screening tool that estimates the amount of stormwater runoff generated from a site and the potential reduction from proposed stormwater management practices. The analysis considers local soil conditions, slope, land cover, and meteorology. Different stormwater management practices can be employed to help capture and retain rainfall on-site. Inputs include project location, stormwater approach, and scale of application. The SWC tool includes a GIS interface and interacts with national databases to upload data for the project area. A low level of stormwater and economic expertise is needed – the tool is very quick and straight-forward to use and can be used to determine the right mix and relative size of stormwater management practices to meet stormwater retention targets. The SWC and guidebook can be accessed through EPA's website.

D.12 US EPA Storm Water Management Model (SWMM)

US EPA SWMM is a software application used for large-scale planning, analysis, and design of stormwater runoff, combined and sanitary sewers, and other drainage systems. It can be used to evaluate gray infrastructure stormwater control strategies, such as pipes and storm drains, and is a useful tool for creating cost-effective green/gray hybrid stormwater control solutions. A high level of stormwater and economic expertise is required for this model. The tool and guidebook are available on the US EPA's website.

Typical applications of SWMM include:

- Designing and sizing of drainage system components for flood control
- Sizing detention facilities and their appurtenances for flood control and water quality protection
- Mapping flood plains of natural channel systems
- Designing control strategies for minimizing combined sewer overflows
- Evaluating the impact of inflow and infiltration on sanitary sewer overflows
- Generating non-point source pollutant loadings for waste load allocation
- Controlling site runoff using GSI practices
- Evaluating the effectiveness of stormwater management practices for reducing wet weather pollutant loadings

D.13 US EPA Visualizing Ecosystems for Land Management Assessment (VELMA) Model

The VELMA tool, developed by the US EPA, is an eco-hydrological model that can be used to help improve the water quality of streams, rivers, and estuaries by making better use of both natural and engineered GSI to control loadings from nonpoint sources of pollution. It is designed to help users assess GSI options for controlling the fate and transport of water, nutrients, and toxics across multiple spatial and temporal scales for different ecoregions and present and future climates. In addition, the tool can be used to quantify co-benefits of GSI practices, specifically tradeoffs among important Improvements to Ecosystem Services.

A high level of stormwater and economic expertise is required for this model. The tool and guidebook are available on the EPA's website.

D.14 US EPA Watershed Management Optimization Support Tool (WMOST)

The WMOST Tool, developed by the US EPA, is a software application designed to facilitate integrated water resources management at the local or watershed scale. The tool allows water resources managers and planners to screen a wide range of stormwater practices across their watershed or jurisdiction for cost-effectiveness and environmental and economic sustainability. Users can identify least-cost solutions to meet water quality criteria for lakes or streams/rivers, pollutant loading targets, and/or minimization of combined sewer overflows.

A high level of stormwater and economic expertise is required for this model. The tool and guidebook are available on the EPA’s website.

D.15 Virginia Department of Environmental Quality Virginia Runoff Reduction Method (VRRM)

The Virginia Department of Environmental Quality developed the VRRM, an Excel-based tool used to determine stormwater runoff volume and pollutant reduction capabilities of various stormwater management typologies. This tool is applicable for communities in Virginia to document compliance with the Virginia Stormwater Management Program regulations. A medium level of stormwater and economic expertise is required for this model. The tool and guidebook are available on the Virginia Department of Environmental Quality’s website. There are separate worksheets for new and redevelopment scenarios.

The tool can be run with minor design inputs (e.g., type of stormwater management practice and area managed within that practice) since it is assumed that the designer will locate and design the stormwater management practice in accordance with the design criteria provided in the Virginia Stormwater BMP Standards and Specifications.

D.16 Water research foundation Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs (CLASIC)

CLASIC is a screening tool that utilizes a lifecycle cost framework to support the planning of green, hybrid green-gray, and gray infrastructure scenarios at the community, watershed, or neighborhood scale. The tool is hosted on a cloud-based web platform and integrated with GIS and national databases. CLASIC allows users to evaluate lifecycle costs, water quality performance, and hydrologic performance. In addition, CLASIC provides quantitative output to compare social and environmental benefits across various user-defined scenarios.

D.17 Water Research Foundation Economic Framework and Tools for Quantifying and Monetizing the Triple Bottom Line Benefits of Green Stormwater Infrastructure (GSI TBL Tool)

The GSI TBL Tool is an Excel-based tool that provides a systematic approach to quantify and monetize the financial, social, and environmental benefits of GSI at the community or neighborhood scale. The co-benefits analyzed include water quality and water supply benefits, ecosystem benefits, energy savings, carbon emission reductions, public health benefits associated with reduced urban heat stress, improved air quality, increased recreational opportunities and green space, enhanced community livability, and green job creation.

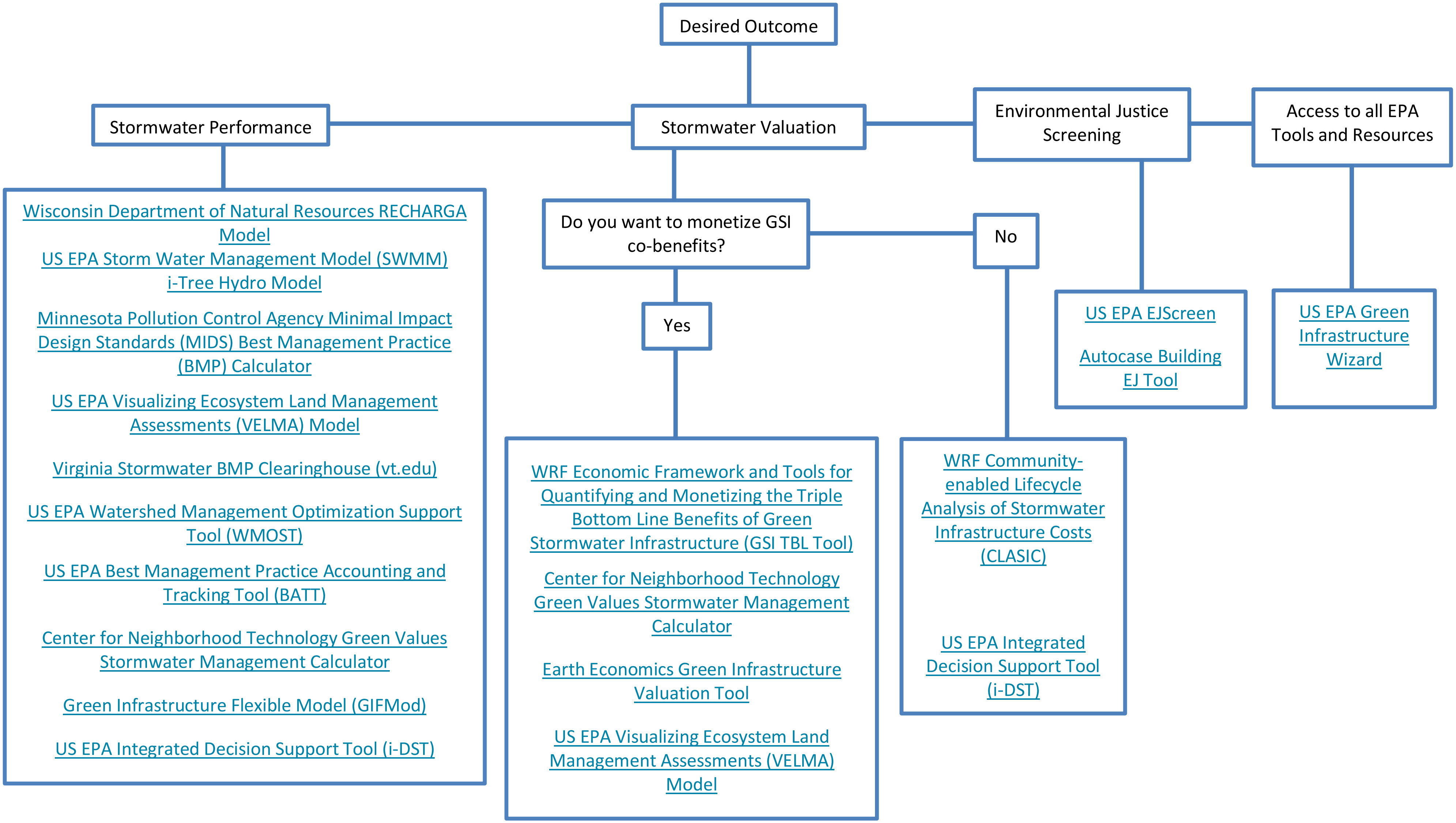
D.18 Wisconsin Department of Natural Resources RECARGA Model

The Wisconsin Department of Natural Resources developed the RECARGA Model to assess GSI performance. The RECARGA Model is a tool used to evaluate the performance of bioretention facilities, rain garden facilities, and infiltration basins. The model continuously simulates the movement of water throughout the facility (e.g., ponding zone, soil layers, and underdrain), records the soil moisture and volume of water in each water budget term at each time step (e.g., infiltration, recharge, overflow, underdrain, evapotranspiration). Inputs include ponding times, number of system overflows, water balance, and plant survivability.

This model can be used to size facilities to meet specific performance objectives, such as reducing runoff volume or increasing recharge, and for analyzing the potential impacts of varying the design parameters. A high level of stormwater and economic expertise is required for this model. The tool and guidebook are available on Wisconsin Department of Natural Resources website.

APPENDIX E

GSI Performance and Valuation Tool Matrix



Desired Outcome

Stormwater Performance

Wisconsin Department of Natural Resources RECHARGA Model
US EPA Storm Water Management Model (SWMM)
i-Tree Hydro Model

Minnesota Pollution Control Agency Minimal Impact Design Standards (MIDS) Best Management Practice (BMP) Calculator

US EPA Visualizing Ecosystem Land Management Assessments (VELMA) Model

Virginia Stormwater BMP Clearinghouse (vt.edu)

US EPA Watershed Management Optimization Support Tool (WMOST)

US EPA Best Management Practice Accounting and Tracking Tool (BATT)

Center for Neighborhood Technology Green Values Stormwater Management Calculator

Green Infrastructure Flexible Model (GIFMod)

US EPA Integrated Decision Support Tool (i-DST)

Stormwater Valuation

Do you want to monetize GSI co-benefits?

Yes

WRF Economic Framework and Tools for Quantifying and Monetizing the Triple Bottom Line Benefits of Green Stormwater Infrastructure (GSI TBL Tool)

Center for Neighborhood Technology Green Values Stormwater Management Calculator

Earth Economics Green Infrastructure Valuation Tool

US EPA Visualizing Ecosystem Land Management Assessments (VELMA) Model

No

WRF Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs (CLASIC)

US EPA Integrated Decision Support Tool (i-DST)

Environmental Justice Screening

US EPA EJScreen

Autocase Building EJ Tool

Access to all EPA Tools and Resources

US EPA Green Infrastructure Wizard

APPENDIX F

Recommendations for Future Updates

Appendix F provides a summary of model errors identified during the case study research and recommendations for improvements.

F.1 CLASIC Model Errors

Below is a listing of specific items that were identified during the case study research within the CLASIC model.

1. For the rain garden practice, the user manual states that filter media porosity is 0.4 and 0.437. It appears that a porosity of 0.4 was used in the calculations.
2. Certain default inputs (% captured and number of practices) could be overridden in the practices tab. This is an error, as the user should only be permitted to modify these default inputs in the technology addition tab during the creation of scenarios.
3. The water quality and water hydrologic performance outputs were not as expected. In the New Orleans and Sun Valley case studies, some of the performance metrics appeared to be backwards. See key takeaways section.

F.2 GSI TBL Tool Errors

Below is a listing of specific items that were identified during the case study research within the CLASIC model.

1. Cells C77, C78 and C79 on the Costs. Timelines tab are all filled in to be 1/3 of footprint installed for permeable pavement options noted in GSI Scenario tab (cell I30). However, the unit costs listed for reference on the cost tab are not the same.
2. The maintenance costs for permeable pavement references permeable concrete but not asphalt or pavers (Cells C77, C78, and C79).
3. When extending construction years >1, the total construction cost becomes greater than if 1 year for certain case studies (Colorado and California both produced different costs when testing).
4. If no ‘managed impervious area’ is included on GSI Scenario tab for Rain Garden or Biofiltration, the tool creates error for benefits and cannot be used.
5. The cost table references volume (cf) for wet ponds but capital cost calculation references footprint (sf) in GSI Scenario tab.

References

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