8. TRIPLE BOTTOM LINE ANALYSIS

The word “sustainability” is commonly described with the term “3P”, which means Planet, People, and Prosperity. Instead of focusing solely on the direct financial impacts of a project, applying a triple bottom line (TBL) analysis adds considerations for environmental and social equity factors to the overall decision-making. Quantifying the environmental and social benefits of a project can be complex, and there is no “one-size-fits-all” approach to apply in all cases. However, applying a TBL approach can result in more holistic, and presumably better, decisions. Figure 8-1 shows the overlapping aspects of the broad categories of environmental, economic, and social benefits and how they converge on sustainability.

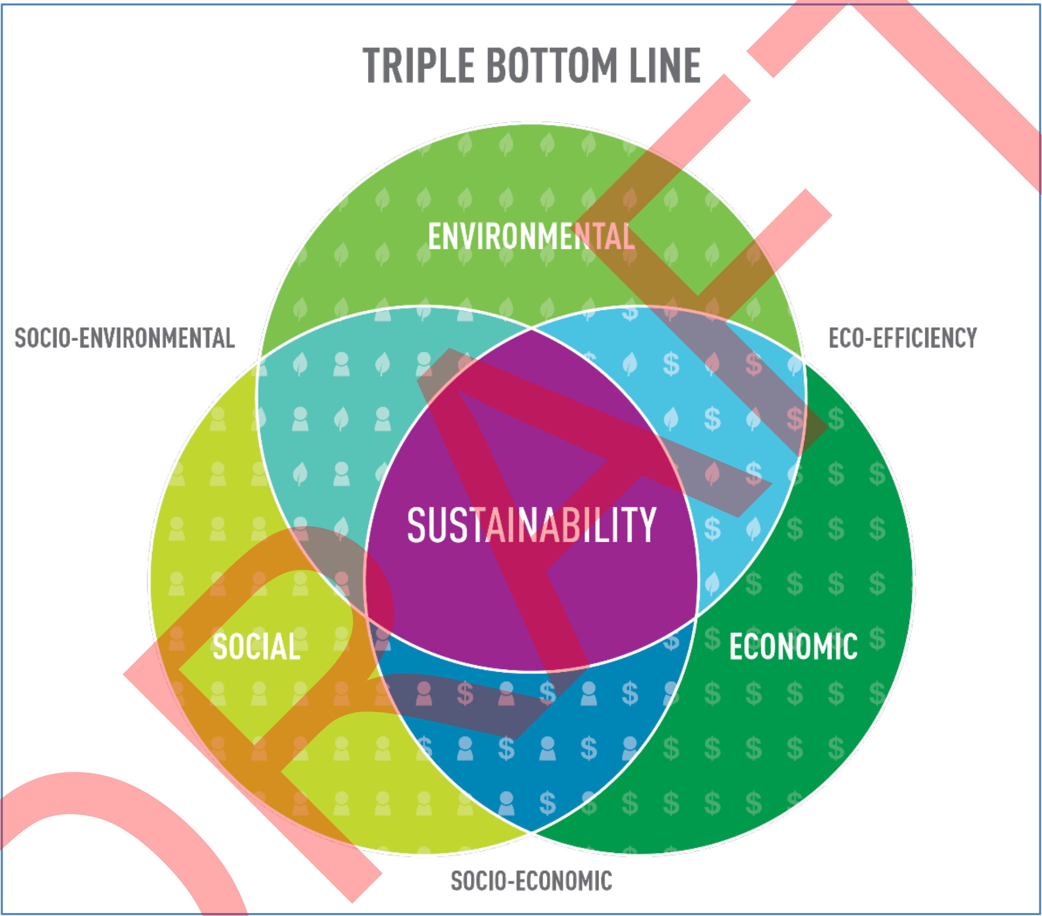

Figure 8-1: Triple Bottom Line Analysis Categories

8.1 Triple Bottom Line Approach

There are several benefit calculation methods, as well as different calculation software, to help quantify TBL benefits. The Envision™ framework is an increasingly used and industry-wide approach to evaluating TBL benefits. Utilizing this defined rating system allows users to evaluate a project according to a common sustainability framework; then TBL software may be used to quantify the potential benefits. For this study, the TBL benefits were quantified using a combination of AutoCASE web-based software and some custom calculations. AutoCASE was chosen as the primary TBL computation software because it is an easy to use and popular TBL software that allows projects to be quickly defined and calculated. Custom calculations were used in cases where an alternative calculation approach was deemed more appropriate than the calculation method applied by AutoCASE. When a custom calculation was used, a description of the approach and a rationale for its use is provided.

8.1.1 Envision Framework

The Envision™ framework is the product of a joint collaboration between the Zofnass Program for Sustainable Infrastructure at the Harvard University Graduate School of Design and the Institute for Sustainable Infrastructure (ISI). Envision™ provides a holistic framework for evaluating and rating the social, environmental, and economic business case of infrastructure projects. It evaluates, grades, and recognizes infrastructure projects that use transformational, collaborative approaches to assess the sustainability indicators over the course of the project's life cycle.

Envision has a variety of assessment tools that can be used by infrastructure owners, design teams, community groups, environmental organizations, constructors, regulators, and policy makers to:

- Assess costs and benefits over the project lifecycle
- Evaluate environmental benefits
- Use outcome-based objectives.
- Reach higher levels of sustainability achievement

AutoCASE was developed in conjunction with the ISI's Economics Committee to enhance the Envision rating system by adding the ability to provide value-based and risk-adjusted TBL analyses of stormwater infrastructure projects. The methodologies and data have been adapted from recent literature quantifying each cost and benefit and can be adjusted for specific locations. AutoCASE uses a Monte Carlo simulation to account for the uncertainty around the tool's inputs and methodologies. This provides users with a probability distribution of potential outcomes, rather than only a single expected value, which can imply a misleading degree of certainty in the results. A summary of the benefit calculations is included below.

8.2 Initial Project Setup

AutoCASE allows a user to manage multiple analyses and projects according to a hierarchical relationship. Numerous projects and design alternatives can be managed under the same analysis folder. Figure 8-2 shows the concept of this analysis management. Within each project, specific design alternatives are filled in with their user defined inputs or the default values included in AutoCASE. After the necessary inputs are provided, an analysis report is provided that compares the alternatives with either the "do nothing" existing condition option or benefits provided by a specific alternative.

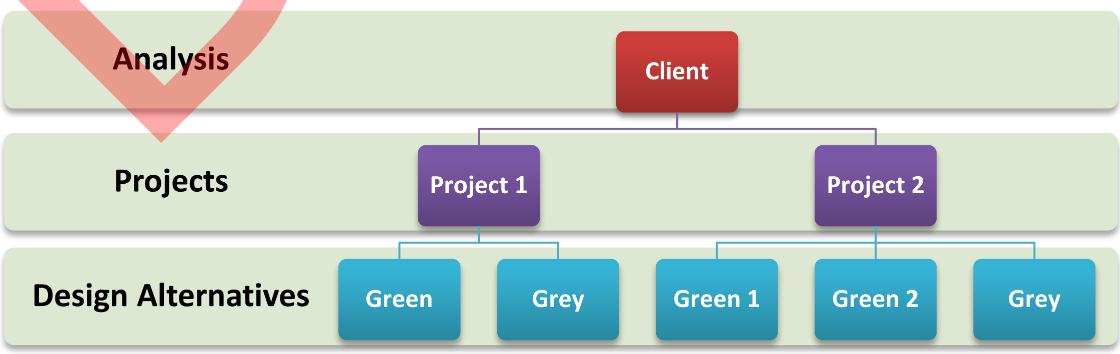

Figure 8-2: AutoCASE Analysis Management

For each design alternative, there are options to select the specific benefits that the user wishes to calculate from a mix of environmental, economic, and social categories. These benefits do not form definite groups, but rather intersect just like the sustainability concept diagram in Figure 8-1.

The benefits categories in the AutoCASE tool are identified in Figure 8-3. For this study, the Air Pollution, Carbon Emission, Heat Island, and Recreational Use benefits were calculated using the AutoCASE tool. Due to the site specific nature and the detailed available information, the flood risk and property uplift benefits are highlighted in red in Figure 8-3 because they were calculated outside of AutoCASE. The wetland benefit is also highlighted because AutoCASE can calculate this benefit, but it was deemed to be not applicable to this investigation. Although economic water quality was analyzed manually using the AutoCASE methodology. Detailed descriptions of AutoCASE's benefit calculations can be found in

Appendix H.

Figure 8-3: Benefits Categories in the AutoCASE Tool

8.3 Project Inputs

Because of the diverse benefits that can be calculated by AutoCASE, there are over 400 potential inputs that can be defined. Having this large number of inputs allows the analyses to be tailored to closely match specific project conditions. Each input impacts at least one of the benefit calculations, and many inputs are used across multiple benefit calculations. Because many of the inputs are only approximately known, AutoCASE also allows the user to input a range of values and relevant probability distributions. These ranges provide the basis for the risk assessment in the model, allowing the user to indicate uncertainty around values. Many of the inputs have default values that are calculated automatically by AutoCASE based on published research or from other input values, but a user can overwrite any of these defaults.

AutoCASE requires three types of inputs to perform its TBL calculations which are classified as design components, common components and additional components. These are further detailed in the following sections.

8.3.1 Design Components

AutoCASE allows evaluation of a wide spectrum of GI feature types that can be evaluated individually or collectively as part of an overall project. As a user selects the design feature(s) that are applicable for their project they input relevant data and answer input questionnaires for the selected design features.

These designs can include both grey and green infrastructure features, and each project can be set up with a combination of these design features, or just have a single feature. These features can also be compared to each other in the results in relative analysis. For the GI evaluation in this project, bioretention was selected as the GI feature for analysis.

8.3.2 Common Components

Within AutoCASE there are nine common component input categories and each category leads to other hierarchy selections or questions for inputs that influence the project's benefits and values. These common inputs must be completed to calculate project benefits. Table 8-1 provides a description of the common inputs required for the benefits analysis.

Table 8-1
Description of Common Inputs for AutoCASE Benefits Analysis

Category	Description
Locations and Dates	This section includes inputs such as the project location, starting date, and operation duration of the project. This section also includes construction and planning inputs that can have significant impacts on benefit calculations.
General Site Questions	This section includes inputs such as infiltration and the 24-hour design storm selected for the site. Currently in AutoCASE, the 24-hour design storm input is not used for calculating flood risk mitigation, but it affects the design of the selected alternatives to be able to handle the runoff volume generated by the design storm.
Jobs, Revenues, and Decommissioning	These inputs are used for capital expenditure's shadow wage allocation. Revenues and decommissioning are not analyzed in this study.
Government Impact	Includes possible restrictions from government entities such as taxes and penalties. These impacts were not included in this study.
Water Quality and Usage	Water Quality and Usage section controls the project's water quality benefit by applying Vaughan's Water Quality Ladder and quantifying its social and environmental value. For this project, the economic aspects of the water quality benefit are manually analyzed using a methodology provided by AutoCASE. The social and environmental water quality benefits were not included in this study.
Other Costs and Benefits	Other Costs and Benefits section is used to calculate site specific benefits outside of AutoCASE that the user would like to directly enter. For this project, the flood risk reduction and property uplift benefits were externally calculated.
Wetland Characteristics	Wetland Characteristics section has several questionnaires to quantify the social and recreational benefits, and to identify potential storm and flood protection additions to the site.
Energy Usage	The Energy Usage component has inputs related to the amount of energy saved or additionally consumed by the design feature choice and the change in use of various energy sectors. This also affects the Carbon Emission reduction and Air Pollution sequestration benefits.
Recreational Use	The Recreational Use section includes questionnaires to help quantify the social benefits due to increased recreational opportunities.

8.3.3 Additional Inputs

There are 6 additional input categories, with multiple questions for each category. Even though this component is stated as "additional", it has critical impact on the benefits calculations. Table 8-2 provides a description of the additional inputs for the benefits analysis.

Table 8-2: Description of the Additional Inputs for AutoCASE Benefits Analysis

Category	Description
General Value Used	This section includes inputs such as population, city/town area, and median house values of the city. For this project, individual City-Wide sewershed projects were created with site specific entries. These inputs have the most impacts in property uplifts benefit analysis. The current AutoCASE method for calculating property uplift has an input of percentage of GI design area within the entire area, rather than the percent of area that would be managed by the design. As a result, the property uplift benefit was calculated outside of AutoCASE using percent of low impact development (LID) retrofitted area, rather the actual ratio of design over the total city area.
Financial Assumptions	The Financial Assumption section includes values such as the discount rate, inflation rate, and taxes that need to be accounted for the duration of the project. For this project the discount rate is set to 4.88% and inflation is set to 4%.
Air Pollution Costs	This section includes the air pollution factors of CO, SO_2, NO_2, $PM_{2.5}$, and O_3 in current year dollars per ton. The default values for this section are calculated with ranges of the increase in vegetated area or the number of trees and shrubs planted. The default values were used for this project.
Carbon Emissions	The Carbon Emissions section includes the discount for the carbon emission, social values, and carbon footprint associated with the project's construction and operation. For this project default values were used for the analysis.
Flood Risk	Variables such as the existing storage volume and additional inputs defining additional drainage areas outside of the project area are included in this section. For this project, the flood risk benefits are calculated outside of AutoCASE and are detailed section 8.4.4.
Green Roof Characteristics and Heat Risk	This section includes values required to compare the difference between traditional grey and green roof impacts to the heat island risk analysis. Since green roofs were not a GI type investigated in this project, this section was not used.

8.4 Triple Bottom Line Benefits and Calculations

AutoCASE has the ability to provide detailed breakdowns of the various costs and benefits computed based on the user-defined inputs and default input values. Not all categories of costs and benefits that are calculable by AutoCASE were implemented for this GI assessment, and some values were computed independently of AutoCASE. Only a subset of the potential calculable benefits were evaluated for this project, the overall TBL benefits calculated later in this section are likely under-estimated. The various result types are detailed below and followed by the computed ranges of costs and benefits of implementing GI solutions across the priority sewersheds.

8.4.1 Air Quality and Carbon Emission

Improvements in air quality are quantified according to the changes in reduction of energy usages from GI project construction and implementation, change in material usages, and increases in vegetated area. The bioretention feature type includes the number of trees and shrubs planted as part of this calculation. Air quality change was computed using the estimated number of trees and shrubs planted and surface area of the increased vegetative cover. Characteristics that could be defined but were not incorporated for this project include electricity generation, green roofs and concrete material usage. The added green space is estimated to be 50% of LID-managed impervious area. The air pollutants reduced in this benefits calculation include carbon monoxide (CO), carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3), and fine particulate matter with diameters 2.5 micrometers or less ($PM_{2.5}$).

8.4.2 Heat Island Mortality Reduction Benefit

AutoCASE uses an enhanced version of the EPA's Value of a Statistical Life (VSL) method to assign value to lives saved from heat mortality as a result of the GI implementation. The temperature reduction or increase of a design alternative is based on changes in surface cover type and were estimated according to the Figure 8-4. Then this information was used to identify avoided death over the life of the project. This number of estimated lives saved was multiplied by the VSL to quantify the financial benefit of the temperature reduction. The limitations of this method include: (1) it does not take into account the non-mortality cases; (2) it does not incorporate additional benefits of having plants over the designed area.

For this study 50% of the GI managed impervious areas are assumed to be additional vegetated areas. The calculation assumes additional green spaces from the new GI, and some areas remain as existing conditions. The benefit calculation does not include reduction in numbers of non-mortality heat-related cases that could be considered benefits as well. The value of temperature reduced throughout the sewersheds was set as 5.35 degrees F, which is the standard value for the bioretention GI method.

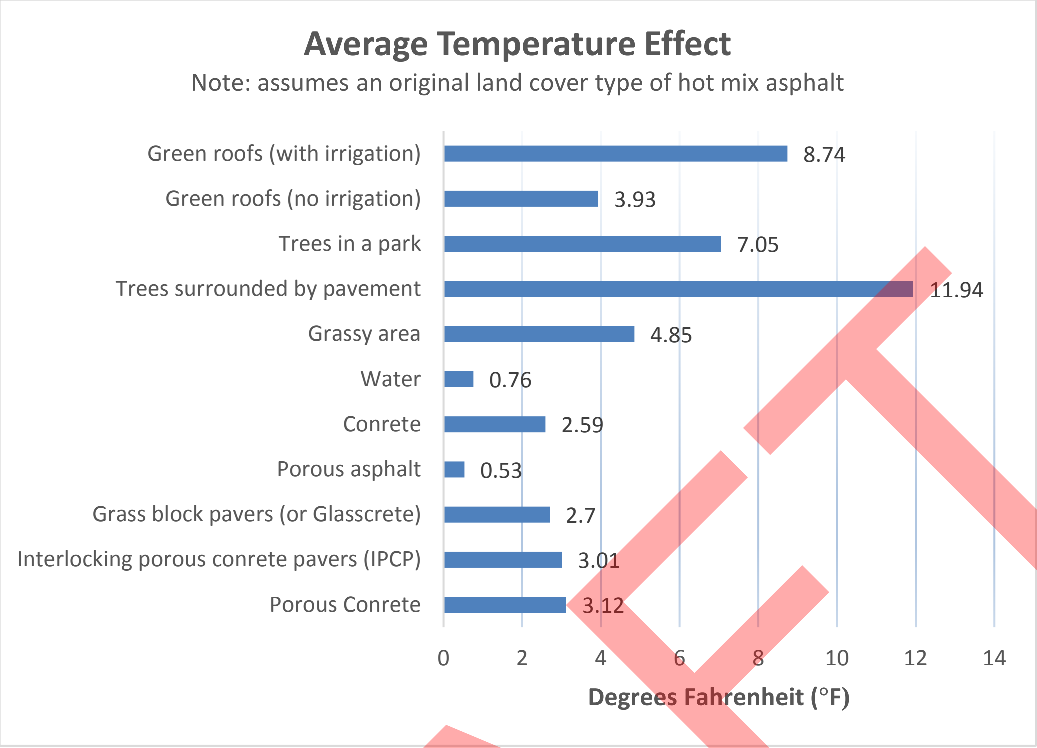

Figure 8-4: Average Temperature Effect of Various GI Types

8.4.3 Recreational Use Benefit

This benefit was calculated by estimating the increased total user days expected after the project is constructed, then multiplying this value by the estimated WTP of users. In this study, the increase in new recreational area within additional vegetated area is estimated to be 75% of retrofitted impervious area. This value can be improved with actual park survey data or site specific increase in recreational usage data if they are available. This benefit could have an increased positive impact if a greater percentage of additional green space is utilized as recreational area, and this varies significantly for every sewershed. For example, if the additional vegetation is created as parking area curves, this area cannot be used for recreation. On the other hand, if the additional green space were for parks, residential developments, or schools to expand their green space, then these would be mostly recreational use, and the recreational benefit can be increased.

8.4.4 Flood Risk Reduction Benefit

The flood risk reduction benefit was calculated separately from AutoCASE. The principal reason for this was to utilize local knowledge of the collection system and of the frequency and number of properties that experience flooding (basement sewage backups during rain events) from more severe storms and limitations of the collection system infrastructure. The key factor in this calculation is determining the number of houses subject to basement sewage backups and the severity of storm event needed to induce backup conditions. The final calculation was based on a combination of historical rainfall analysis, model simulation results, and questionnaires to property owners in the Shadyside neighborhood in the A-22 sewershed to get direct feedback about experiences with basement sewage backup conditions. After a historical review of storm events that have occurred in 50 years, the frequency of storms that are expected to result in basement sewage backup conditions was calculated. Analysis of the A-22 sewershed indicated basement sewage backup conditions under approximately a 4 inches/hour rainfall intensity over a period of 15 minutes. Using this estimate for the starting point of basement backup occurrence, the likelihood of basement backups across the 30 priority sewersheds was estimated. However, it is recognized that predicting the occurrences of basement sewage backups is difficult, even with local knowledge and that many factors can influence when these conditions occur that cannot be predicted. However, this approach for this calculation was deemed to be the most defensible methodology with the data that was readily available.

8.4.5 Property Value Uplift Benefit

The property value uplift benefit is calculated based on the population, number of houses, and the property values that can benefit from the GI project. In this report, percent of LID according to the LID modeling is incorporated as property value uplift due to percentage of LID managed and retrofitted area rather than actual design to city ratio. The property uplift rate of 3.5% was selected based on Philadelphia Water Department (PWD)'s experience (*A Triple Bottom Line Assessment of Traditional and Green Infrastructure Options for Controlling CSO Events in Philadelphia's Watersheds, Stratus Consulting, Inc., 2009*), and to avoid double counting, a 50% multiplier is included in this calculation. This benefit is especially site specific, and a sum of the smaller area calculations are more beneficial rather than one large area. Up-to-date census information is useful for more realistic results. The limitation is that even though one area is divided into smaller regions, it is still difficult to incorporate the demographic gap within the region. If the region has a significant gap of maximum and minimum property value, the uplift calculation might not reflect the entire region.

This benefit was calculated manually as a one-time benefit manually to involve the appropriate percent GI-managed area, rather than computing a ratio of design area to study area. In this way, the GI area is not limited to one location; rather, the GI could be distributed throughout the impervious area. The difference in the Property Value Uplift benefits in the two scenarios was because of the difference in managed LID area. This result also varied with land usage of the sewersheds. Densely populated residential areas had higher benefits than commercial areas or low population areas. One of the most influential factors that could be added in future work to refine the Property Value Uplift benefit calculation is to incorporate the demographic and economic difference within the area. For example, a single sewershed can have residents with widely varying socioeconomic status. The current property uplift calculation has a single average house price, but in the future the equation could be modified if it is identified that the amount of impact by GI could be different in subareas of the sewershed. In addition, additional local survey data can be beneficial to enhance the calculation because uplift rates are different throughout the nation. In this study, the range of uplift rate used was 2.12% to 4.37%, with 3.14% as the expected rate. Areas with a lower median house price could experience a larger impact with GI and other expected social development along with green construction. On the other hand, a high cost of living area might experience less impact compared to other areas.

In this study, population was used to calculate number of households in the area, and multiplied by the median house price. So, higher house prices and greater population in an area results in larger benefit values compared to an area with relatively lower house prices and lower population. It was also found that commercial and industrial areas such as O-41 had the lowest percentage of benefit from property uplift.

8.4.6 Economic Water Quality Benefit

AutoCASE calculates the water quality environmental and social benefit by estimating the change in water quality. In this study, only the economic water quality benefit was calculated because there were no water quality impact results available to identify the change in water quality. AutoCASE provided economic water quality benefit calculations to utilize the possible impact benefit by the design feature with the design storm volume. This method estimated source loadings according to the AutoCASE selections, then estimated changes in runoff and pollutant loadings from the GI elements.

This benefit analysis was computed to target just the economic water quality impact by calculating pollutant amounts that are removed from GI implementation, and monetizing by amount of pollutant. Each design feature has different amounts of pollutant removal levels and in this study, the benefit was estimated in accordance with applying bioretention as the GI method. If water quality improvement data is available, AutoCASE has a feature to calculate the social and environmental benefits of water quality.

Average rainfall data over a 60 year period was used to conduct this analysis to calculate amounts of runoff volume that are managed by the GI. The pollutants that are monetized are total suspended solids, total phosphorus, total Kjeldahl nitrogen, total zinc, total lead, and total copper. During construction, a 10% gain of benefit was assumed every year. The GI operation period was assumed to have full benefit every year.

8.5 TBL Quantified Results

The TBL benefits were calculated across the 30 priority sewersheds for two different levels of GI implementation representing the expected range of GI implementation needed to meet the 85% combined sewage capture goal in each of the sewersheds. Because the TBL benefits are only derived from GI investments, any changes in WWTP capacity or deep interceptor conveyance are not relevant in computing TBL benefits. These two levels of GI investment are:

- 1,286 acres of impervious area managed by GI in 13 sewersheds.
- 1,835 acres of impervious area managed by GI in 18 sewersheds.

The TBL analysis considered the variety of sizes, demographic conditions, and land usages of the sewersheds targeted for impervious area management. Table 8-3 shows the seven TBL benefit categories and the individual and total TBL benefits, represented as net present value (NPV), for managing 1,286 acres of impervious area with GI in 13 sewersheds. Individual sewershed results are listed in Appendix H.

Table 8-3: 50-Year TBL Benefits (Net Present Value) for 1,286 Acres of Directly Connected Impervious Area Managed by GI

Category	90% Confidence Interval NPV	
	Low Range	High Range
Air Pollution Reduced by Vegetation	$5,070,000	$9,180,000
Carbon Reduced by Vegetation	$710,000	$2,960,000
Flood Risk Reduction	$333,130,000	$666,260,000
Heat Island Effect Reduction	$3,020,000	$6,750,000
Property Value Increase	$33,120,000	$68,270,000
Recreational Value Addition	$9,880,000	$15,550,000
Economic Water Quality Benefit	$7,280,000	$9,780,000
Total TBL Benefit	**$392,210,000**	**$778,750,000**
Total TBL Benefit without Flood Risk Reduction	**$59,080,000**	**$112,490,000**

Table 8-4 shows the seven TBL benefit categories values and the individual and total TBL benefits for managing 1,835 impervious acres with GI in 18 sewersheds. Individual sewershed results are listed in Appendix H.

Table 8-4:
50-Year TBL Benefits (Net Present Value) for 1,835 Acres of Directly Connected Impervious Area Managed by GI

Category	90% Confidence Interval NPV	
	Low Range	High Range
Air Pollution Reduced by Vegetation	$7,260,000	$13,090,000
Carbon Reduced by Vegetation	$1,010,000	$4,220,000
Flood Risk Reduction	$335,750,000	$671,500,000
Heat Island Effect Reduction	$4,280,000	$9,610,000
Property Value Increase	$54,770,000	$112,900,000
Recreational Value Addition	$14,120,000	$22,210,000
Economic Water Quality Benefit	$10,390,000	$13,950,000
Total TBL Benefit	**$427,580,000**	**$847,480,000**
Total TBL Benefit without Flood Risk Reduction	**$91,830,000**	**$175,980,000**

Table 8-5 summarizes the estimated pollutant reduction for the six pollutants for the two scenarios.

Table 8-5
Pollutant Reductions for Different Impervious Acres Managed by GI (Bioretention)

Pollutant	Pollutant Removal (lbs) – Directly Connected Impervious Area (DCIA) Managed by GI	
	1,286 DCIA Acres	1,835 DCIA Acres
Total Suspended Solids	782,899	1,117,010
Total Phosphorus	13,327	19,014
Total Kjeldahl Nitrogen	32,417	46,251
Total Zinc	720	1,028
Total Lead	77	110
Total Copper	257	367

8.6 Conclusions

Both levels of GI implementation provide significant TBL benefits across the seven benefits categories. The computed TBL benefits are expected to range between $390M and $850M with a majority of the benefit value from the flood reduction benefit. However, even without including this benefit the TBL benefits would still range between $60M and $175M for the two GI implementation levels.