Triple Bottom Line Cost Benefit Analysis of Green Infrastructure/Low Impact Development (GI/LID) in Phoenix, AZ

Results Report

Prepared by Autocase for the City of Phoenix

June 20th, 2018

Glossary of Terms

BCR	Benefit Cost Ratio
CBA	Cost Benefit Analysis
CAC	Criteria Air Contaminants
CapEx	Capital Expenditure
CBA	Cost Benefit Analysis
CO_2e	Carbon dioxide equivalent
EPA	U.S. Environmental Protection Agency
eGrid	Emissions grid
GHG	Greenhouse Gas
GWP	Global Warming Potential
M	Million
MWh	Megawatt-hour(s)
NPV	Net Present Value
NO_x	Nitrogen Oxide
N_2O	Nitrous Oxide
PM	Particulate Matter
$PM_{2.5}$	Particulate Matter Smaller than 2.5 micrometres
SO_2	Sulfur Dioxide
TBL	Triple Bottom Line
TBL-CBA	Triple Bottom Line-Cost Benefit Analysis
TBL-NPV	Triple Bottom Line-Net Present Value
USD	U.S. Dollars
VOCs	Volatile Organic Compounds

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1 Introduction

1.1 Project Background

Stantec, Autocase, and Watershed Management Group (WMG) were engaged by the City of Phoenix (City) – with The Nature Conservancy (TNC) as a contributing and reviewing partner – to perform a triple bottom line cost benefit analysis (TBL-CBA) of various Green Infrastructure/Low Impact Development (GI/LID) features, as well as look at the triple bottom line impacts of three case study sites in the area.

The TBL-CBA business case was conducted in Autocase - a cloud-based software tool, to provide insights into the net present value (NPV) of costs and benefits of the projects to the City, as well as the broader societal and environmental impacts over a 50-year time horizon using a 3% discount rate to convert all future cash flows into a present value.

TBL-CBA is a systematic evidence-based economic business case framework that uses best practice Life Cycle Cost Analysis and Cost Benefit Analysis (CBA) techniques to quantify and attribute monetary values to the Triple Bottom Line (TBL) impacts resulting from an investment. TBL-CBA expands the traditional financial reporting framework (such as capital, and operations and maintenance costs) to also consider social and environmental performance. TBL-CBA provides an objective, transparent and defensible economic business case approach to assess the costs and benefits pertaining to the project being analyzed.

This study provides information for City projects and private development that may want to implement and incorporate GI/LID facilities. The costs and co-benefits of GI/LID features in the Phoenix environment need to be evaluated to identify the benefits and aid in potentially identifying to which stakeholders they accrue. The City identified key motivating factors for this study, as follows:

1. The need to evaluate the following key parameters:
    a. Financial costs and benefits;
    b. Carbon emissions and air pollution;
    c. Heat island impacts;
    d. Water quality improvement;
    e. Flood risk reduction;
    f. Property value uplift.
2. The need to identify and ensure a common understanding of benefits vs. initial costs vs. life cycle costs
3. The need to provide recommendations on appropriate feature types according to associated costs and benefits.

Given the importance of heat stress in Phoenix, instead of using historical temperatures this report incorporates future climate change in to its analysis. Taking the emissions pathway RCP8.5 “higher emissions” scenario from NOAA’s climate explorer (NOAA, 2018), the analysis incorporates future temperature and rainfall predictions for Maricopa County in to Autocase. In so doing, the results will aid in resilience decision-making related to urban heat island.

Local data were used whenever possible and available; information from various sources, such as EPA's SUSTAIN database and the National Stormwater Management Calculator was used to supplement any gaps and are identified throughout the report.

1.2 Report Structure

This report consists of two analyses: one for the general 1,000 sq ft feature types, and one for the three case study sites.

In Chapters 2 and 3 are the project description and results for the general feature analysis, which investigates generalized costs (on a per-1,000 sq ft basis) and benefits of six feature types that may be utilized in the City of Phoenix. The features that will be analyzed are:

1. Concrete
2. Swale
3. Bioretention basin
4. Infiltration trench
5. Pervious pavers
6. Porous concrete
7. Porous asphalt

In Chapters 4 and 5 are the project description and results for three GI/LID case studies, which looks at costs and benefits of three specific projects previously implemented in the Phoenix Metro area (Primera Iglesia, Glendale Community Center, and a combined project of Central Station/Civic Space Park/Taylor Mall).

A combined Conclusion and Policy Analysis section intended to help the City of Phoenix make broad decisions on overall GI/LID feature implementation in Phoenix, while recognizing that projects should be evaluated on an individual basis to determine TBL results and which features might be most beneficial for specific sites. Information on specific methodology used for the analyses is included in Section 8.

1.3 Project Parameters

The specific parameters – or impacts – to be assessed for each feature type (including concrete) in Autocase are:

Impact Type	Cost/Benefit
Financial	Capital Expenditures (CapEx)
Financial	Operations and Maintenance (O&M)
Financial	Avoided CapEx on Additional Detention
Financial	Avoided O&M on Additional Detention
Financial	Avoided CapEx on Additional Piping
Financial	Avoided O&M on Additional Piping
Financial	Replacement Costs
Financial	Residual Value of Assets
Social	Heat Island Effect (Mortality)
Social	Heat Island Effect (Morbidity)
Social	Flood Risk
Social	Property Value
Environmental	Water quality
Environmental	Carbon Emissions from Concrete
Environmental	Air Pollution Reduced by Vegetation
Environmental	Carbon Reduction by Vegetation
Environmental	Air Pollution from Energy Use Reduction
Environmental	Carbon Emissions from Energy Use Reduction

A description of each parameter and the associated valuation methodology is included in Section 8.3.

1.4 Summary of Feature Costs

Table 1 outlines the capital expenditure (CapEx) and annual operations and maintenance (O&M) costs that are used to evaluate the features throughout the report. Details on their sources and how they were derived is given within each feature's description below. Local and site-specific values were used where possible. If those were not available, either Autocase estimates were used (informed by EPA's SUSTAIN database), or the National Stormwater Management Calculator values were used.

Table 1: Summary of Feature Costs

Feature		Unit	Cost ($)		
			Low	Expected	High
Concrete	CapEx	$ per 1,000 sq ft	$4,500	$5,750	$7,000
	O&M	$ per 1,000 sq ft	$0	$0	$0
Swale	CapEx	$ per 1,000 sq ft	$1,124	$5,527	$11,358
	O&M	$ per 1,000 sq ft	$97	$120.95	$151
Porous concrete	CapEx	$ per 1,000 sq ft	$6,370	$7,000	$10,670
	O&M	$ per 1,000 sq ft	$12	$24	$48
Bioretention basin	CapEx	$ per 1,000 sq ft	$2,000	$3,000	$4,000
	O&M	$ per 1,000 sq ft	$97	$121	$151
Infiltration trench	CapEx	$ per 1,000 sq ft	$400	$1,450	$4,200
	O&M	$ per 1,000 sq ft	$97	$121	$151
Pervious pavers	CapEx	$ per 1,000 sq ft	$7,540	$12,970	$17,800
	O&M	$ per 1,000 sq ft	$12	$24	$48
Underground stormwater storage	CapEx	$ per 1,000 cubic ft	$904	$1,205	$1,506
	O&M	$ per 1,000 cubic ft	$1	$1	$6
Trees	CapEx	$ per tree	$160	$591	$739
	O&M	$ per tree	$12	$16	$20
Planter boxes	CapEx	$ per 1,000 sq ft	$550	$8,000	$24,500
	O&M	$ per 1,000 sq ft	$97	$121	$151
Retention basin	CapEx	$ per 1,000 cubic ft	$4,260	$11,550	$22,710
	O&M	$ per 1,000 cubic ft	$15	$30	$60
Porous asphalt	CapEx	$ per 1,000 sq ft	$2,840	$6,330	$9,470
	O&M	$ per 1,000 sq ft	$12	$24	$48
Shrubs	CapEx	$ per 1,000 sq ft	$109	$218	$355
	O&M	$ per 1,000 sq ft	-	-	-

Notes:
- **O&M for shrubs is included within the O&M cost of specific features (e.g., bioretention basin, bioswale, etc.).**

1.5 Common Inputs

The following section illustrates the inputs used for the project, including information about the city, the financial assumptions, and specifications about each feature type analyzed with Autocase. These variables were kept standard across all feature type evaluations.

Table 2: Common Inputs

Input	Unit	Value	Notes
Dominant soil type		B	
24-hour design storm	Inches	1	A 0.5-inch and 2-inch storm were also assessed, with results for these analyses in Section 10.1 and 10.2.
Stormwater model		TR-55	
Operations duration	Years	50	
Construction duration	Years	1	
Discount rate	%	3%	

2 Project Description (GI/LID Feature Types)

This section outlines the GI/LID feature types that are analyzed in this report, as well as states the more detailed design assumptions used in order to generate results within Autocase.

2.1 Features to be Analyzed

The list of GI/LID features to be analyzed in this general feature analysis section are:

1. **Rain garden/Bioretention basin:** shallow earthen depressions that collect stormwater runoff into native soils to support planted vegetation.
2. **Swale:** rock or vegetated swales are open, shallow channels that are designed to slowly convey runoff flow to downstream discharge points.
3. **Infiltration trench:** a channel-like subsurface excavation that has been filled with gravel to provide large pore spaces for stormwater to infiltrate.
4. **Pervious pavers:** Also called interlocking porous concrete pavers, these permeable surfaces use the spaces between the pavers to infiltrate water and can be designed to reduce peak runoff.
5. **Porous concrete:** a specific type of concrete with a high porosity used for flat work applications that allows rainfall to pass directly through and infiltrate the soil below.
6. **Porous asphalt:** allows rainfall to drain through the surface into a stone recharge bed and infiltrate the soil below.

Each of these features were analyzed individually against the key parameters through Autocase to evaluate 'standalone' costs and benefits. They each were then compared against a base case 'Concrete' feature type in Autocase to assess their *incremental* or *relative* impact. The concrete base case was chosen to reflect a more typical 'gray' site. To be able to compare and evaluate the various feature types, it was important this analysis use consistent control variables. Therefore, the size of each feature (including concrete) was kept consistent at 1,000 square feet, and a 15:1 watershed area was used to represent the surface area that would generate runoff flowing in to each feature. The same design storm event and other similar variables (detailed in Section 2.3.2–Common Inputs) were also kept consistent so any changes in costs/benefits would be attributable to the feature type.

2.2 Project Inputs

The following section illustrates the inputs used for the feature type analysis, such as depths, storage volume, and cost information.

2.2.1 Base Case Design Specifications (Concrete)

Concrete was used as the base case against which the GI/LID feature types were compared. This means the costs and benefits for the base case were assessed assuming that 1,000 sq ft of new concrete was constructed instead of a GI/LID feature.

Table 3: 1,000 sq ft Feature Type Concrete Inputs

	Unit	Expected Value
Name of feature		Concrete
Area	Sq ft	1,000
Depth of coverage material	Inches	3
CapEx	$	$5,750 (Low = $4,500, High = $7,000)
Annual O&M	$	$0

Notes:

- The low CapEx cost of $4,500 is for areas greater than 1,000 sq ft. The high CapEx cost of $7,000 is for areas less than 1,000 sq ft.
- Per City of Phoenix Street Maintenance Division, operation and maintenance costs for concrete sidewalk is $0 because no recurring maintenance is required. It is instead fully replaced when damaged/deteriorated. The average life for a concrete sidewalk in Phoenix (barring external forces) is 25-30 years. This is factored in to the life cycle cost model in Autocase and is reflected in the replacement cost.

2.2.2 GI/LID Feature Type Design Specifications

2.2.2.1 Swale

Table 4: 1,000 sq ft Feature Type Porous Swale Inputs

	Unit	Expected Value
Name of feature		Swale
Area	Sq ft	1,000
Maximum Ponding/Treatment Depth	Inches	9
Channel Bank Height	Inches	2
Soil type		B
Maximum Surface Infiltration Rate	Inches per hour	4.5
Minimum Surface Infiltration Rate	Inches per hour	0.25
Infiltration Rate Reduction Factor	per hour	1
Capital Expenditure	$	$5,527 (Low = $1,124, High = $11,358)
Annual O&M	$	$121 (Low = $97, High = $151)

Notes:

- Based off the swale at Taylor Mall, 2nd to 3rd Street. Using Google Earth (address of 444 N. Central Avenue) to count trees and estimate shrubs and note the concrete curb and curb cut, fine grading within planting area; and using the plan sheets and cost lines. Used the plan sheets to measure lengths and widths.
- CapEx: Low does not include concrete removal or the concrete single curb, but does include 1 tree, 8 shrubs, 8 feet of curb cuts. Expected does not include concrete removal, but does include concrete single curb, 2 trees, 16 shrubs, 16 feet of curb cuts. High includes concrete removal, concrete single curb, 3 trees, 26 shrubs, 24 feet of curb cuts (8 openings, 3' each).
- O&M costs are from Watershed Management Group estimates based on $120/1,000 sq. ft. at a rate of $75/hr (low/high = +/- 25%).

Figure 1: Swale
Source: City of Phoenix, Office of Environmental Programs.

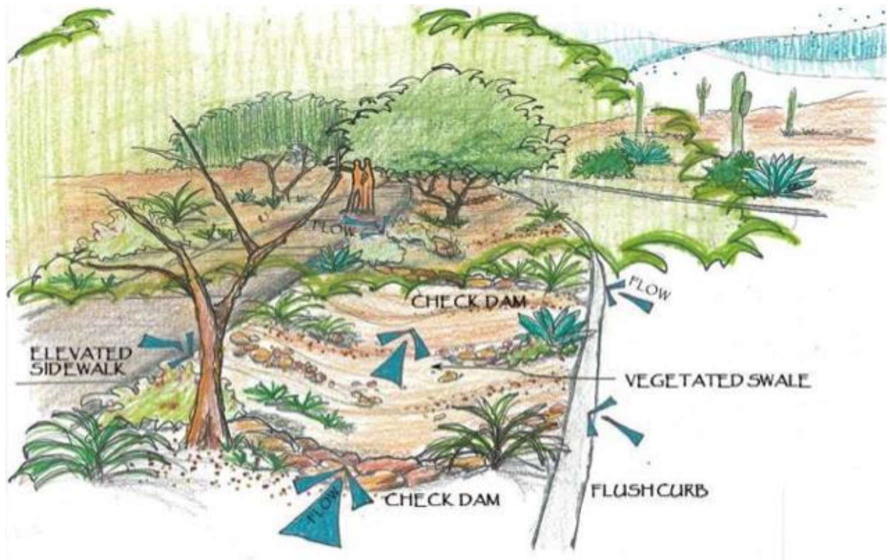

Figure 2: Elements of a Swale
Source: PIMA County, 2015. "Low Impact Development and Green Infrastructure Guidance Manual".

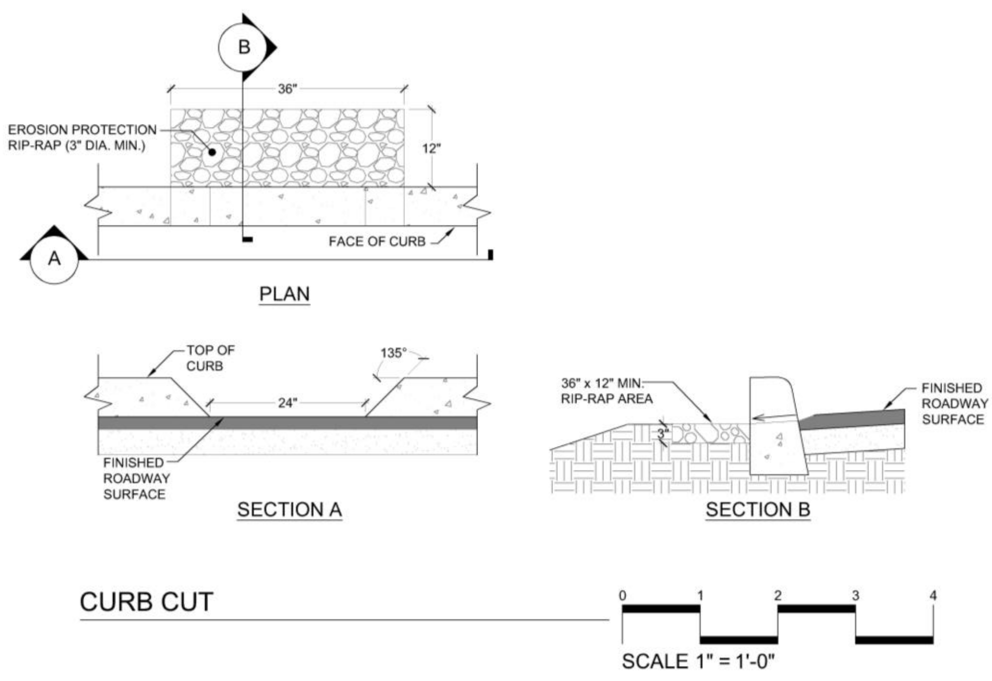

Figure 3: Typical Curb Cut Design Detail
Source: WMG
Notes: Swales may use curb cuts to draw in water in to the feature, thus its inclusion here.

2.2.2.2 Bioretention Basin/Rain Garden

Table 5: 1,000 sq ft Feature Type Bioretention Basin Inputs

	Unit	Expected Value
Name of feature		Bioretention/Rain garden
Area	sq ft	1,000
Maximum Ponding/Treatment Depth	Inches	6
Depth of Coverage Materials	Inches	3
Percent Empty Space in Material	%	40
Does this feature allow for infiltration?		Yes
Trees Planted	#	3
Shrubs planted	#	28
Shrubs Average Expected Lifespan	Year	10
Shrubs Max Expected Lifespan	Year	20
Soil type		B
Maximum Surface Infiltration Rate	Inches per hour	4.5
Minimum Surface Infiltration Rate	Inches per hour	0.25
Infiltration Rate Reduction Factor	per hour	1
CapEx	$	$3,000 (Low = $2,000, High = $4,000)
Annual O&M	$	$121 (Low = $97, High = $151)

Notes:

- Capital costs for Bioretention Basins are based on WMG's experience over the last decade in Tucson as well as the last 5 years in Phoenix designing and constructing basins. Costs include labor, design, curb cuts, shrubs, grasses, trees, rock and/or wood mulch, permitting, excavation and soil hauling. Costs vary depending on existing site conditions such as topography, land use, hardscape and soil type as well as if a curb cut is needed.
- O&M costs are from Watershed Management Group estimates based on $120/1,000 sq ft at a rate of $75/hr.

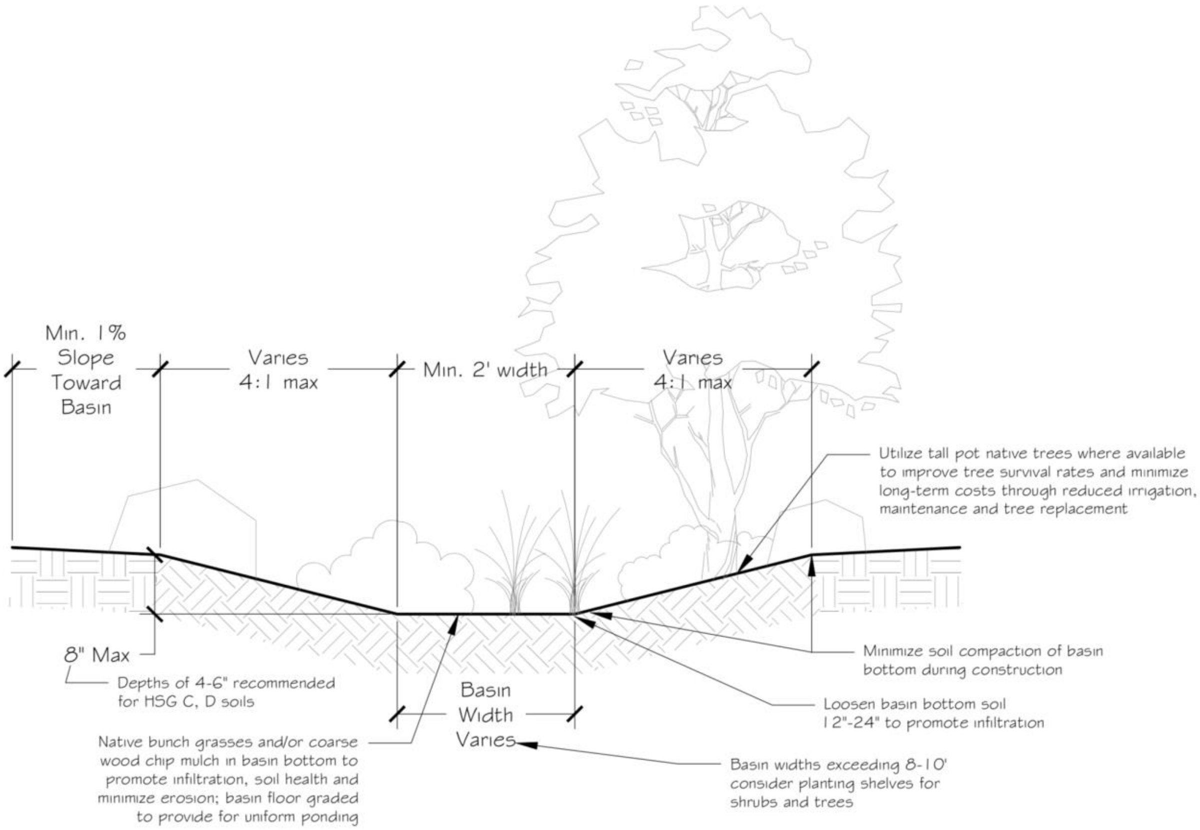

Figure 4: Typical Bioretention Basin Cross-section
Source: Watershed Management Group

Figure 5: Bioretention Basin
Source: City of Phoenix, Office of Environmental Programs.

2.2.2.3 Infiltration Trench

Table 6: 1,000 sq ft Feature Type Infiltration Trench Inputs

	Unit	Expected Value
Name of feature		Infiltration Trench
Area	sq ft	1,000
Depth of Coverage Materials	Inches	24
Percent Empty Space in Material	%	40
Rate of Gray Discharge from Outlet of Feature	-	-
Soil type		B
Maximum Surface Infiltration Rate	Inches per hour	4.5
Minimum Surface Infiltration Rate	Inches per hour	0.25
Infiltration Rate Reduction Factor	per hour	1
Capital Expenditure	$	$1,450 (Low = $400, High = $4,200)
Annual O&M	$	$120 (Low = $97, High = $151)

Notes:

- CapEx is from EPA's SUSTAIN database and includes: backfilling, excavation, filter fabric, grading/finishing, grass, gravel, mulch, observation well, perennials, soil/planting media.
- O&M costs are from Watershed Management Group estimates based on $120/1,000 sq ft at a rate of $75/hr.

Figure 6: Infiltration Trench
Source: PIMA County, 2015. "Low Impact Development and Green Infrastructure Guidance Manual".

2.2.2.4 Pervious Pavers

Table 7: 1,000 sq ft Feature Type Pervious Pavers Inputs

	Unit	Expected Value
Name of feature		Pervious pavers
Area	Sq ft	1,000
Depth of Coverage Materials	Inches	3
Percent Empty Space in Material	%	20
Rate of Gray Discharge from Outlet of Feature	-	-
Soil type		B
Maximum Surface Infiltration Rate	Inches per hour	4.5
Minimum Surface Infiltration Rate	Inches per hour	0.25
Infiltration Rate Reduction Factor	per hour	1
Capital Expenditure	$	$12,970 (Low = $7,540, High = $17,800)
Annual O&M	$	$24 (Low = $12, High = $48)

Notes:
- CapEx: Expected = using Taylor Mall 100 Plan Cost Model. Low and High from SUSTAIN.
- O&M costs calculated from Glendale Park and Ride at 99th Ave, which is porous concrete. O&M cost for power washing for FY 2017 was $2,580 across an area of 214,053 sq ft. Low = 1 wash per year, Expected = 2 times per year, High = 4 times per year.

Figure 7: Pervious Pavers (Interlocking Porous Concrete Pavers)
Source: City of Phoenix, Office of Environmental Programs.

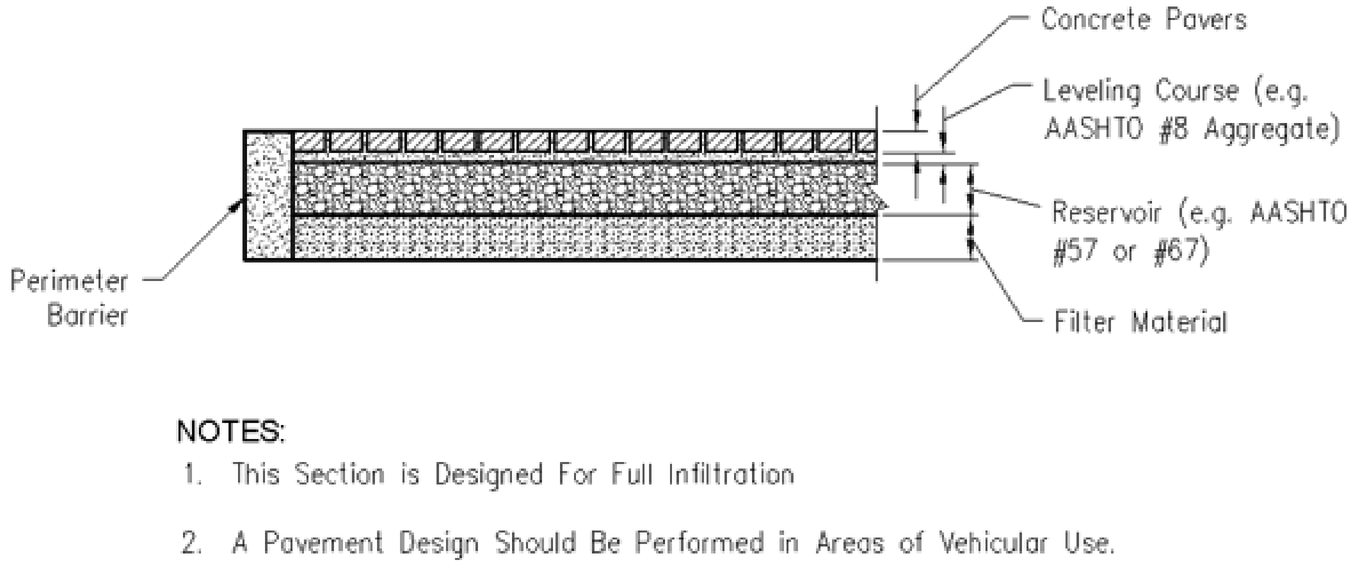

Figure 8: Design Detail for Typical Pervious Pavers
Source: PIMA County, 2015. "Low Impact Development and Green Infrastructure Guidance Manual".

2.2.2.5 Porous Concrete

Table 8: 1,000 sq ft Feature Type Porous Concrete Inputs

	Unit	Expected value
Name of feature		Porous concrete
Area	Sq ft	1,000
Depth of Coverage Materials	Inches	4
Percent Empty Space in Material	%	20
Rate of Gray Discharge from Outlet of Feature	-	0
Soil type		B
Maximum Surface Infiltration Rate	Inches per hour	4.5
Minimum Surface Infiltration Rate	Inches per hour	0.25
Infiltration Rate Reduction Factor	per hour	1
Capital Expenditure	$	$7,000 (Low = $6,370, High = $10,670)
Annual O&M	$	$24 (Low = $12, High = $48)

Notes:

- CapEx: Expected = Site specific cost from the line items taken from Central Station Upgrades. Low and High values taken from SUSTAIN.
- O&M costs calculated from Glendale Park and Ride at 99th Ave, which is porous concrete. O&M cost for power washing for FY 2017 was $2,580 across an area of 214,053 sq ft. Low = 1 wash per year, Expected = 2 times per year, High = 4 times per year

Figure 9: Example Porous Concrete Installation
Source: City of Phoenix, Office of Environmental Programs

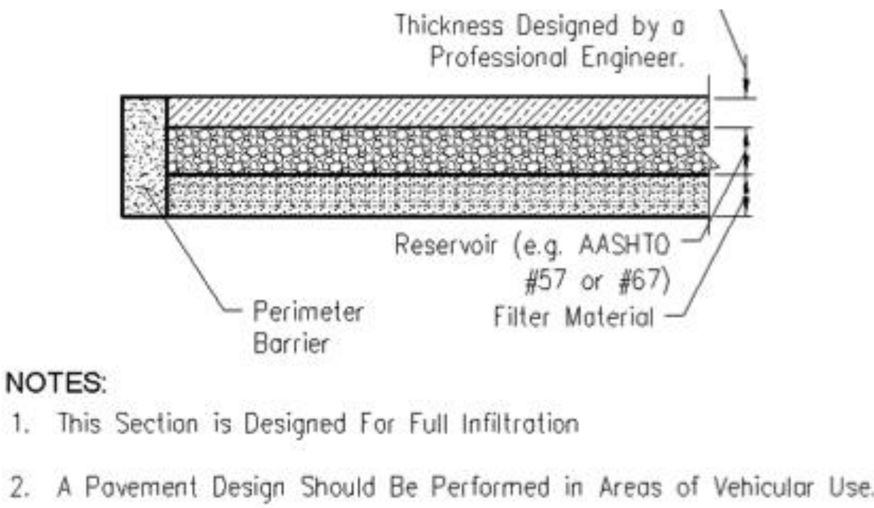

Figure 10: Porous Concrete Detail
Source: PIMA County, 2015. "Low Impact Development and Green Infrastructure Guidance Manual".
Note: Taken from page 117. In the source above, the picture says "Pervious Concrete Pavers but is referring to porous concrete.

2.2.2.6 Porous Asphalt

Table 9: 1,000 sq ft Feature Type Asphalt Inputs

	Unit	Expected Value
Name of feature		Porous asphalt
Area	Sq ft	1,000
Depth of Coverage Materials	Inches	3
Percent Empty Space in Material	%	20
Rate of Gray Discharge from Outlet of Feature	-	-
Soil type		B
Maximum Surface Infiltration Rate	Inches per hour	4.5
Minimum Surface Infiltration Rate	Inches per hour	0.25
Infiltration Rate Reduction Factor	per hour	1
Capital Expenditure	$	$6,330 (Low = $2,840, High = $9,470
Annual O&M	$	$24 (Low = $12, High = $48).

Notes:

- Autocase default from SUSTAIN including: Excavation, Filter Fabric, Grading/finishing, Gravel, Observation Well, and Underdrain Pipe.
- O&M costs calculated from Glendale Park and Ride at 99th Ave, which is porous concrete. O&M cost for power washing for FY 2017 was $2,580 across an area of 214,053 sq ft. Low = 1 wash per year, Expected = 2 times per year, High = 4 times per year.

Figure 11: Porous Asphalt
Source: Stantec

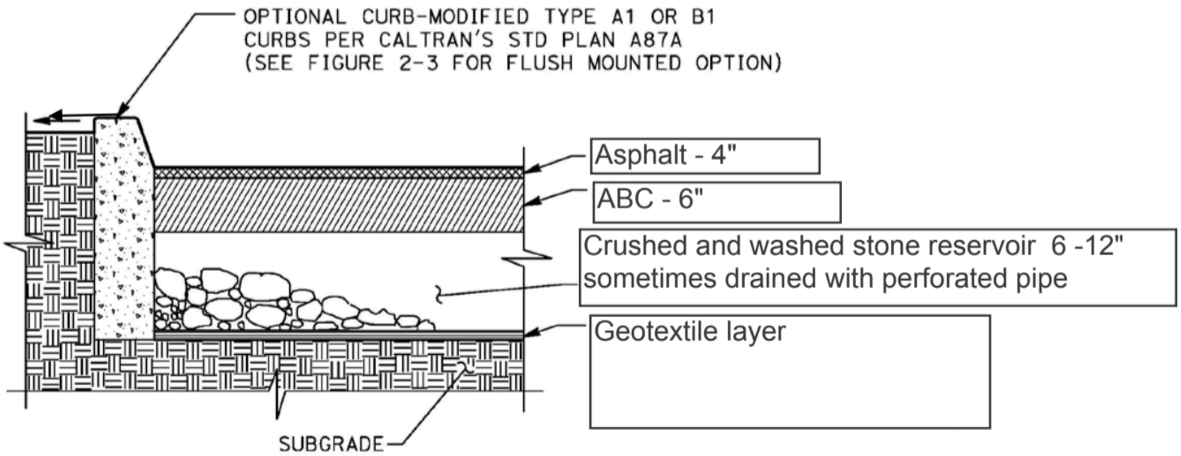

Figure 12: Design Detail for Typical Asphalt
Source: Stantec

3 Triple Bottom Line Net Present Value Results (GI/LID Feature Types)

This Section provides an overview of the results of the general feature type analysis that was presented in the previous section. Dollar amounts reflect costs and benefits estimated for the full 50-year life cycle used for each feature where the area of each feature is 1,000 square feet.

The tables and graphs that follow show the total cost of ownership of each feature, along with the social and environmental benefits that are generated over the 50-year time horizon. Negative numbers represent a cost or disbenefit (financial, social, or environmental), whereas positive numbers illustrate a saving or benefit; the larger the number, the greater the cost or benefit.

3.1 Summary of Results

3.1.1 Summary of Results Absolute

A summary of the Absolute financial, social, and environmental impacts for each feature type are given in Table 10. Absolute values are those that address each feature type individually without reference or comparison to the base case of concrete. Figure 13 represents these results visually.

From a purely financial perspective, Concrete (-$7,400), Bioretention basins (-$7,600) and Infiltration trenches (-$5,500) are the least expensive to build and operate over 50 years, whereas Pervious pavers are the most expensive (-$18,500). From a social perspective, Swales and Bioretention basins generate the most social impact at around $11,800 and $11,700, respectively. Concrete ($1,800), Infiltration trench ($1,200), and Porous asphalt ($1,000) generate the least social benefit. In terms of environmental benefits, Swale and Bioretention basin both generate the most environmental benefits at around $4,300 each over 50 years. The Concrete feature generates the worst impact at -$3,200. Looking at the overall TBL-NPV, we can see that only Swale and Bioretention basin are positive ($6,200 and $8,300). The largest negative TBL-NPVs are Concrete, Pervious pavers, and Porous asphalt at -$8,800 and -$14,200, and -$6,600 respectively.

We must note that these are Absolute results, and in order to make a comparison against a base case of Concrete, we need to identify the incremental differences between each LID feature and the base case of Concrete (i.e. a Relative analysis).

Table 10: Summary of Absolute Triple Bottom Line Results ($/1,000 sq ft)

	Concrete (base case)	Swale	Bioret'n Basin	Infiltration Trench	Pervious Pavers	Porous Concrete	Porous Asphalt
Financial	-$7,426	-$9,856	-$7,627	-$5,465	-$18,494	-$10,638	-$9,563
Social	$1,809	$11,775	$11,655	$1,165	$2,364	$2,623	$1,019
Environmental	-$3,176	$4,313	$4,300	$1,661	$1,912	$1,912	$1,912
Triple Bottom Line NPV	**-$8,793**	**$6,233**	**$8,328**	**-$2,638**	**-$14,218**	**-$6,102**	**-$6,632**

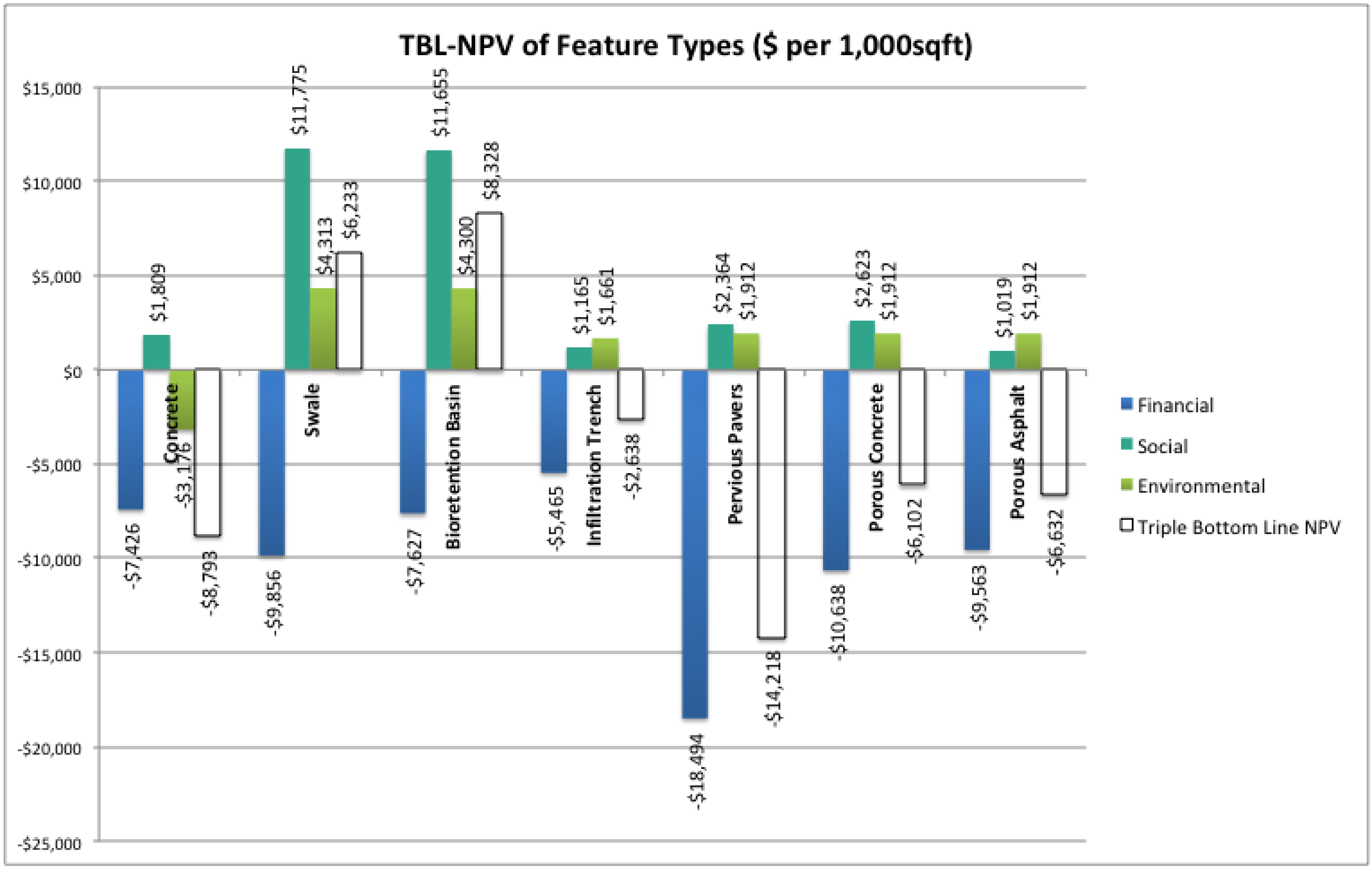

Figure 13: Absolute TBL-NPV Results of Feature Types ($ per 1,000 sq ft)

3.1.2 Summary of Results: Relative

A summary of the Relative – or incremental (i.e. versus Concrete base case) financial, social, and environmental impacts for each feature type are given in Table 11. Figure 14 offers a visual representation of these.

From a purely financial perspective, only Infiltration trench is cheaper than concrete over 50 years at around $2,000 in savings. All other features are more expensive, with Pervious pavers are about $11,100 more expensive per 1,000 sq ft. In terms of social impacts, Swale and Bioretention basin stand out as winners – generating almost an additional $10,000 each. Only Infiltration trench and Porous asphalt generate negative social impacts at -$600 and -$800. Environmentally, all features perform better than Concrete[1], with Swale and Bioretention basin each generating around $7,500 additional benefit, while the lowest – Infiltration trench still generates almost $5,000 more than Concrete. Finally, in terms of TBL-NPV, all but Pervious pavers (-$1,000) generate positive TBL-NPV, with Swale ($15,000) and Bioretention basin ($17,100) the clear leaders.

Table 11: Summary of Relative Triple Bottom Line Results Compared to Concrete ($/1,000 sq ft)

	Swale	Bioretent'n Basin	Infiltration Trench	Pervious Pavers	Porous Concrete	Porous Asphalt
Financial	-$2,429	-$200	$1,962	-$11,067	-$3,211	-$2,136
Social	$9,966	$9,846	-$644	$555	$814	-$790
Environmental	$7,489	$7,476	$4,837	$5,088	$5,088	$5,088
Triple Bottom Line NPV	**$15,026**	**$17,122**	**$6,155**	**-$5,424**	**$2,691**	**$2,162**

[1] The environmental benefits are consistently large across the features; this is primarily due to two factors: 1) avoided carbon from concrete production being the same across the board; and 2) the similar infiltration rates of the features, which feeds into the flood risk and water quality benefits. Both these impacts generate large value (as will be seen in the detailed tables below).

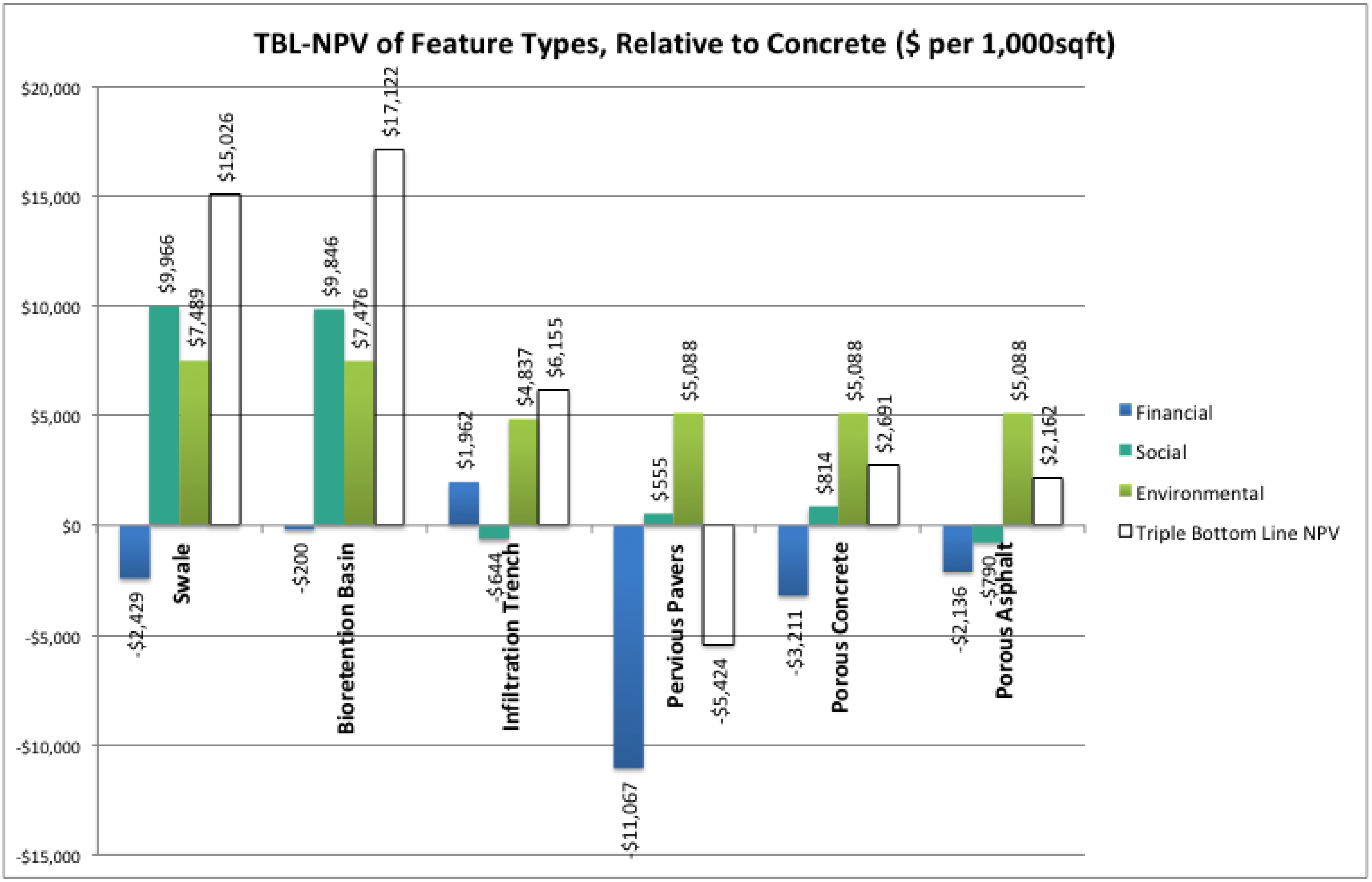

Figure 14: TBL-NPV Results of Feature Types Relative to Concrete ($ per 1,000 sq ft)

3.2 Detailed results

Table 12 breaks down the Absolute results for the feature types by each impact type – or parameter. Table 13 provides the Relative (i.e. vs. concrete) value for each feature by impact type. For a more detailed breakdown of the results, which include the 95% confidence intervals for each cost and benefit, please see the following sections. Positive numbers represent a benefit or value generation, while negative numbers are additional costs or dis-benefit generated.

3.2.1 Detailed Results: Absolute

From Table 12, we can dive deeper to identify the driving forces of value for each feature on an absolute basis. For example, from a financial perspective we can see that O&M for Swale (-$3,200), Bioretention basin (-$3,200), and Infiltration Trench (-$3,100) are a considerable cost factor compared to their CapEx, whereas Replacement cost are a dominant force for Pervious pavers (-$6,000), Porous concrete (-$2,800), and Porous asphalt (-$3,100). From a social perspective, Swale and Bioretention basin generate significant Heat island effect benefits at around $10,000 each.

Environmentally, the biggest water quality benefits are created by Swale ($2,700) and Bioretention basin ($2,600), however Pervious pavers, Porous concrete, and Porous asphalt still generate almost $2,000 each. The use of Concrete generates carbon emissions valued at around -$3,200. Swale and Bioretention basin also generate benefits from reduced CO_2 and air pollution caused by vegetation as well as lower energy use.

Table 12: Absolute TBL-CBA Values for Each Feature by Impact Type ($/1,000sq ft)

Impact Type	Cost/Benefit	Concrete (Base Case)	Swale	Bioret'n Basin	Infiltrat'n Trench	Pervious Pavers	Porous Concrete	Porous Asphalt
Financial	Capital Expenditures	-$5,796	-$5,820	-$3,022	-$1,715	-$12,976	-$7,596	-$6,321
Financial	Operations and Maintenance	$0	-$3,165	-$3,170	-$3,115	-$676	-$675	-$675
Financial	CapEx on Additional Detention	-$24	$0	$0	$0	$0	$0	0
Financial	O&M on Additional Detention	-$6	$0	$0	$0	$0	$0	0
Financial	CapEx on Additional Piping	-$505	$0	$0	$0	$0	$0	0
Financial	O&M on Additional Piping	-$76	$0	$0	$0	$0	$0	0
Financial	Replacement Costs	-$1,452	-$1,371	-$1,662	-$672	-$5,906	-$2,788	-$3,124
Financial	Residual Value of Assets	$431	$501	$227	$38	$1,064	$422	$558
Social	Heat Island Effect (Mortality)	$1,807	$10,041	$10,369	$0	$1,753	$1,997	$409
Social	Heat Island Effect (Morbidity)	$2	$6	$6	$1	$2	$2	$0
Social	Flood Risk	$0	$1,421	$1,151	$1,036	$481	$495	$481
Social	Property Value	$0	$308	$129	$128	$129	$129	$129
Environmental	Water quality	$0	$2,682	$2,629	$1,661	$1,912	$1,912	$1,912
Environmental	Carbon Emissions from Concrete	-$3,176	$0	$0	$0	$0	$0	0
Environmental	Air Pollution Reduced by Vegetation	$0	$1,033	$1,080	$0	$0	$0	0
Environmental	Carbon Reduction by Vegetation	$0	$76	$70	$0	$0	$0	0
Environmental	Air Pollution Reduced by Energy Use	$0	$290	$290	$0	$0	$0	0
Environmental	Carbon Reduction by Energy Use	$0	$231	$231	$0	$0	$0	0
Total:	**TBL-NPV**	**-$8,793**	**$6,233**	**$8,328**	**-$2,638**	**-$14,218**	**-$6,102**	**-$6,632**

3.2.2 Detailed Results: Relative

Table 13 enables us to see where benefits – or dis-benefits – are being created relative to a Concrete base case. Looking at the financial impacts, some interesting factors emerge. In terms of CapEx, Swale costs roughly the same as Concrete, Bioretention basin and Infiltration trench cost less by around $2,800 and $4,100, respectively, while Pervious pavers cost about $7,200 more per 1,000 sq ft. For O&M, all features are more expensive than Concrete; Swale, Bioretention basin, and Infiltration trench cost around $3,000 more over 50 years, while Pervious pavers, Porous concrete, and Porous asphalt only cost around $700 more due to the lack of vegetation maintenance associated with them. We also see that there are small cost savings ($600) associated with additional piping and detention for all features versus Concrete.

Regarding social factors, we can see that the vegetated features i.e. Swale and Bioretention generate significant heat island effect benefits compared to Concrete. By factoring in future temperature predictions using NOAA's Climate Explorer, we can see how each feature will impact heat risk mortality under higher temperatures than those currently felt. Infiltration trench and Porous asphalt create disbenefits compared to Concrete from heat risk mortality due to their darker surface. For flood risk, given that all features have a higher infiltration rate compared to Concrete, each one generates a benefit, with the vegetated features creating the most ($1,000 to $1,500) compared to Pervious pavers, Porous concrete, and Porous asphalt ($500).

There are some significant environmental benefits created by GI/LID features when compared to Concrete. Firstly, water quality improvements due to reduced runoff range from around $2,700 for Swale to almost $2,000 for Porous concrete. Each feature achieves a benefit of around $3,200 in avoided carbon emissions from Concrete. Lastly, the Swale and Bioretention basin each generate around $1,600 in reduced carbon emissions and air pollution from vegetation and avoided energy use due to shading.

Table 13: Relative TBL-NPV Results for Each Feature by Impact Type Compared to Concrete ($/1,000 sq ft)

Impact Type	Cost/Benefit	Swale	Bioret'n Basin	Infiltrat'n Trench	Pervious Pavers	Porous Concrete	Porous Asphalt
Financial	Capital Expenditures	-$24	$2,774	$4,081	-$7,180	-$1,800	-$526
Financial	Operations and Maintenance	-$3,165	-$3,170	-$3,115	-$676	-$675	-$675
Financial	CapEx on Additional Detention	$24	$24	$24	$24	$24	$24
Financial	O&M on Additional Detention	$6	$6	$6	$6	$6	$6
Financial	CapEx on Additional Piping	$505	$505	$505	$505	$505	$505
Financial	O&M on Additional Piping	$76	$76	$76	$76	$76	$76
Financial	Replacement Costs	$81	-$210	$780	-$4,454	-$1,336	-$1,672
Financial	Residual Value of Assets	$69	-$204	-$394	$633	-$10	$126
Social	Heat Island Effect (Mortality)	$8,233	$8,562	-$1,807	-$55	$190	-$1,398
Social	Heat Island Effect (Morbidity)	$4	$4	-$1	$0	$1	-$1
Social	Flood Risk	$1,421	$1,151	$1,036	$481	$495	$481
Social	Property Value	$308	$129	$128	$129	$129	$129
Environmental	Water quality	$2,682	$2,629	$1,661	$1,912	$1,912	$1,912
Environmental	Carbon Emissions from Concrete	$3,176	$3,176	$3,176	$3,176	$3,176	$3,176
Environmental	Air Pollution Reduced by Vegetation	$1,033	$1,080	$0	$0	$0	$0
Environmental	Carbon Reduction by Vegetation	$76	$70	$0	$0	$0	$0
Environmental	Air Pollution Reduced by Energy Use	$290	$290	$0	$0	$0	$0
Environmental	Carbon Reduction by Energy Use	$231	$231	$0	$0	$0	$0
Total:	**TBL-NPV**	**$15,026**	**$17,122**	**$6,155**	**-$5,424**	**$2,691**	**$2,162**

3.3 Swales

Swales generate an estimated $15,026 (95% confidence interval of -$2,151 to $33,600) in triple bottom line net present value over a 50-year time horizon relative to Concrete, with -$2,400 created through financial impacts, $10,000 through social benefits, and $7,500 through environmental benefits.

Figure 15 shows a waterfall chart of the breakdown of these values. On the chart, blue represents value being created, whereas red represents a cost, relative to concrete. We can see that Swales have almost no incremental capital expenditure (CapEx) but do have higher operations & maintenance (O&M) costs compared to Concrete. We can see that varying amounts of value are created across the social and environmental spectrum of impacts, with the most significant being heat island benefit ($8,200), flood risk ($1,400), water quality ($2,700), and avoided carbon emissions from concrete use ($3,200).

The 95% confidence intervals shown in Table 14 allow us to see the uncertainty in some of these figures. For example, CapEx and Replacement costs could be higher or lower than Concrete. There is a large spread in heat island benefits ($4,603 to $12,005), as well as water quality ($453 to $5,561), and when all impacts have been assessed it creates a large spread in overall TBL-NPV (-$2,151 to $33,600) but reveals a small chance of generating a negative TBL-NPV as compared to Concrete.

Financial	Social	Environmental
-$2,429	$9,966	$7,489

Triple Bottom Line NPV	**$15,026**

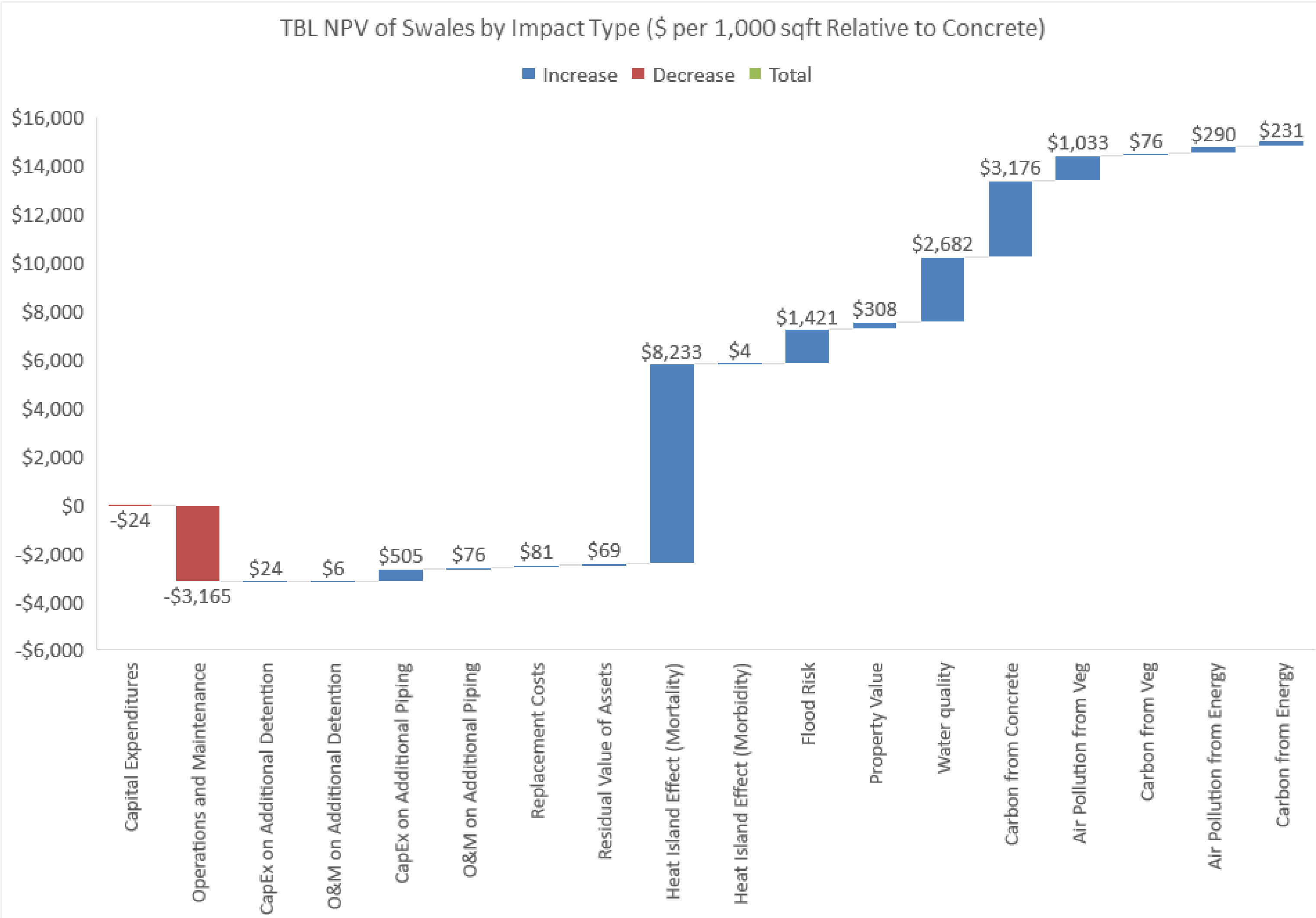

Figure 15: Breakdown of TBL NPV for Swales

Table 14: Swale Relative Results Compared to Concrete with 95% CI ($/1,000 sq ft)

Impact Type	Cost/Benefit	Mean Value	95% Confidence Interval		
Financial	Capital Expenditures	**-$24**	-$4,802	to	$4,188
Financial	Operations and Maintenance	**-$3,165**	-$3,650	to	-$2,675
Financial	CapEx on Additional Detention	**$24**	$9	to	$39
Financial	O&M on Additional Detention	**$6**	$0	to	$11
Financial	CapEx on Additional Piping	**$505**	$403	to	$642
Financial	O&M on Additional Piping	**$76**	$45	to	$110
Financial	Replacement Costs	**$81**	-$2,290	to	$2,589
Financial	Residual Value of Assets	**$69**	-$820	to	$1,058
Social	Heat Island Effect (Mortality)	**$8,233**	$4,603	to	$12,005
Social	Heat Island Effect (Morbidity)	**$4**	-$2	to	$12
Social	Flood Risk	**$1,421**	$1,408	to	$1,433
Social	Property Value	**$308**	$205	to	$429
Environmental	Water quality	**$2,682**	$453	to	$5,561
Environmental	Carbon Emissions from Concrete	**$3,176**	$1,294	to	$5,771
Environmental	Air Pollution Reduced by Vegetation	**$1,033**	$696	to	$1,380
Environmental	Carbon Reduction by Vegetation	**$76**	$31	to	$140
Environmental	Air Pollution Reduced by Energy Use	**$290**	$173	to	$460
Environmental	Carbon Reduction by Energy Use	**$231**	$94	to	$451

Total	**Triple Bottom Line NPV**	**$15,026**	-$2,151	to	$33,604

3.4 Bioretention Basin

Bioretention basin generates an estimated $17,122 (95% confidence interval of $4,300 to $32,300) in triple bottom line net present value over a 50-year time horizon relative to Concrete, with -$200 created through financial impacts, $9,800 through social benefits, and $7,500 through environmental benefits.

Figure 16 shows a waterfall chart of the breakdown of these values. On the chart, blue represents value being created, whereas red represents a cost, relative to concrete. We can see that Bioretention basins have a lower CapEx than Concrete but is outweighed by higher O&M. Varying amounts of value are created across the social and environmental spectrum of impacts, with the most significant being heat island benefit ($8,600), flood risk ($1,200), water quality ($2,600), and avoided carbon emissions from concrete use ($3,200).

The 95% confidence intervals shown in Table 15 allow us to see the uncertainty in some of these figures. There is a large spread in heat island benefits ($4,831 to 12,440), as well as water quality ($444 to $5,451), and when all impacts have been assessed it creates a large spread in overall TBL-NPV of $4,307 to $32,254; nevertheless, even at the low estimate we still generate a positive TBL-NPV as compared to Concrete.

Financial	Social	Environmental
-$200	$9,846	$7,476

Triple Bottom Line NPV	**$17,122**

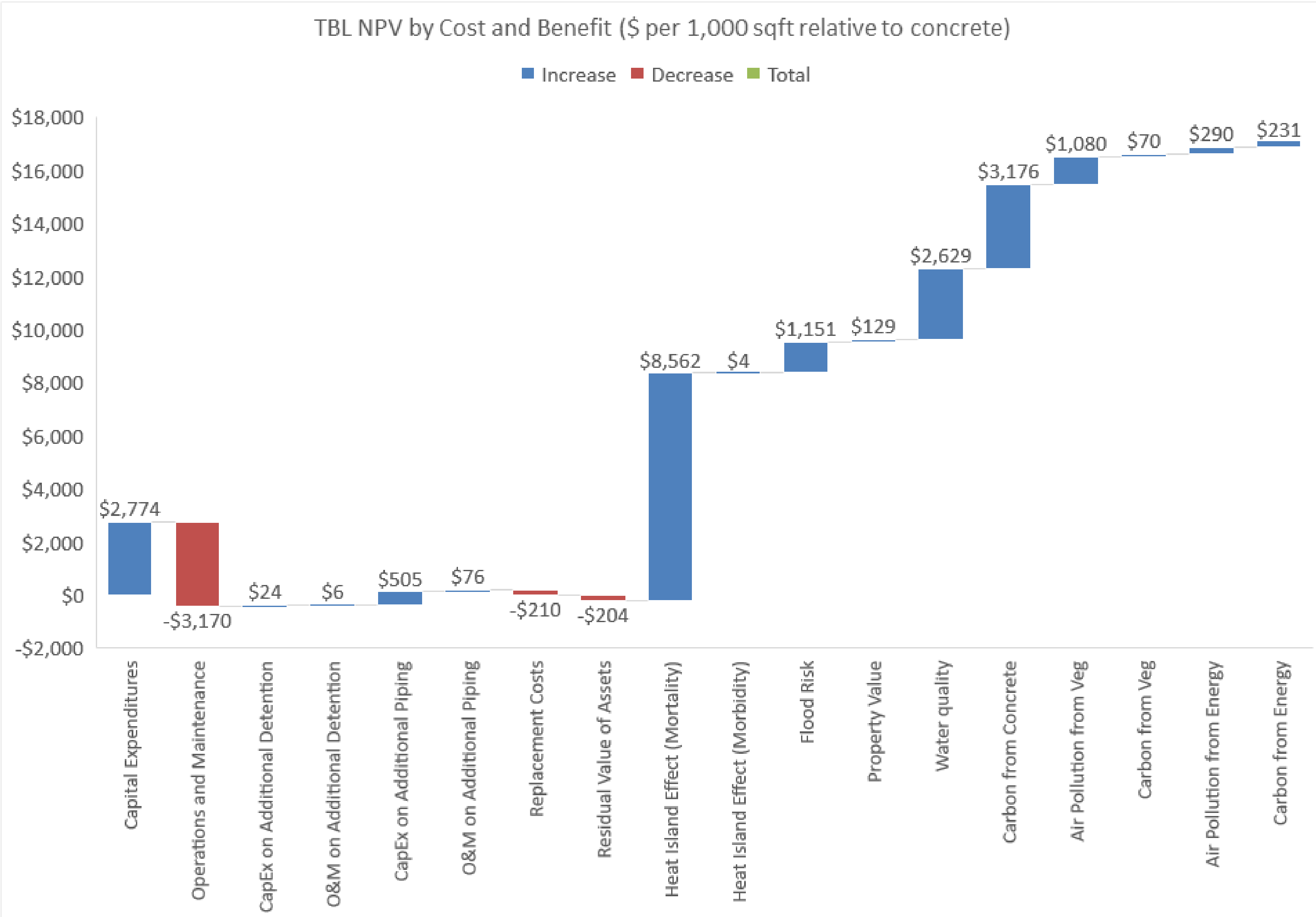

Figure 16: Breakdown of TBL NPV for Bioretention Basins

Table 15: Bioretention Basin Relative Results Compared to Concrete with 95% CI ($/1,000 sq ft)

Impact Type	Cost/Benefit	Mean Value	95% Confidence Interval		
Financial	Capital Expenditures	**$2,774**	$1,133	to	$4,400
Financial	Operations and Maintenance	**-$3,170**	-$3,662	to	-$2,680
Financial	CapEx on Additional Detention	**$24**	$9	to	$39
Financial	O&M on Additional Detention	**$6**	$0	to	$11
Financial	CapEx on Additional Piping	**$505**	$403	to	$642
Financial	O&M on Additional Piping	**$76**	$45	to	$110
Financial	Replacement Costs	**-$210**	-$1,713	to	$1,978
Financial	Residual Value of Assets	**-$204**	-$723	to	$266
Social	Heat Island Effect (Mortality)	**$8,562**	$4,831	to	$12,440
Social	Heat Island Effect (Morbidity)	**$4**	-$2	to	$12
Social	Flood Risk	**$1,151**	$1,138	to	$1,163
Social	Property Value	**$129**	$81	to	$183
Environmental	Water quality	**$2,629**	$444	to	$5,451
Environmental	Carbon Emissions from Concrete	**$3,176**	$1,294	to	$5,771
Environmental	Air Pollution Reduced by Vegetation	**$1,080**	$732	to	$1,428
Environmental	Carbon Reduction by Vegetation	**$70**	$29	to	$129
Environmental	Air Pollution Reduced by Energy Use	**$290**	$173	to	$460
Environmental	Carbon Reduction by Energy Use	**$231**	$94	to	$451
Total	**Triple Bottom Line NPV**	**$17,122**	$4,307	to	$32,254

3.5 Infiltration Trench

Infiltration trench generates an estimated $6,200 (95% confidence interval of -$2,601 to $15,815) in triple bottom line net present value over a 50-year time horizon relative to Concrete, with $2,000 created through financial savings, -$600 through social impacts, and $4,800 through environmental benefits.

Figure 17 shows a waterfall chart of the breakdown of these values. On the chart, blue represents value being created, whereas red represents a cost, relative to concrete. We can see that Infiltration trenches have a lower CapEx than Concrete; this saving outweighs the higher O&M. Varying amounts of value (as well as dis-benefits) are created across the social and environmental spectrum of impacts, with the most significant being heat island benefit (-$1,800), flood risk ($1,000), water quality ($1,700), and avoided carbon emissions from concrete use ($3,200).

The 95% confidence intervals shown in Table 16 allow us to see the uncertainty in some of these figures. There is a large spread in CapEx ($1,471 to $6,056), as well as water quality ($280 to $3,444), and when all impacts have been assessed it creates a large spread in overall TBL-NPV of -$2,601 to $15,815, showing that there is a possibility – albeit small – of negative TBL-NPV compared to Concrete.

Financial	Social	Environmental
$1,962	-$644	$4,837
Triple Bottom Line NPV		**$6,155**

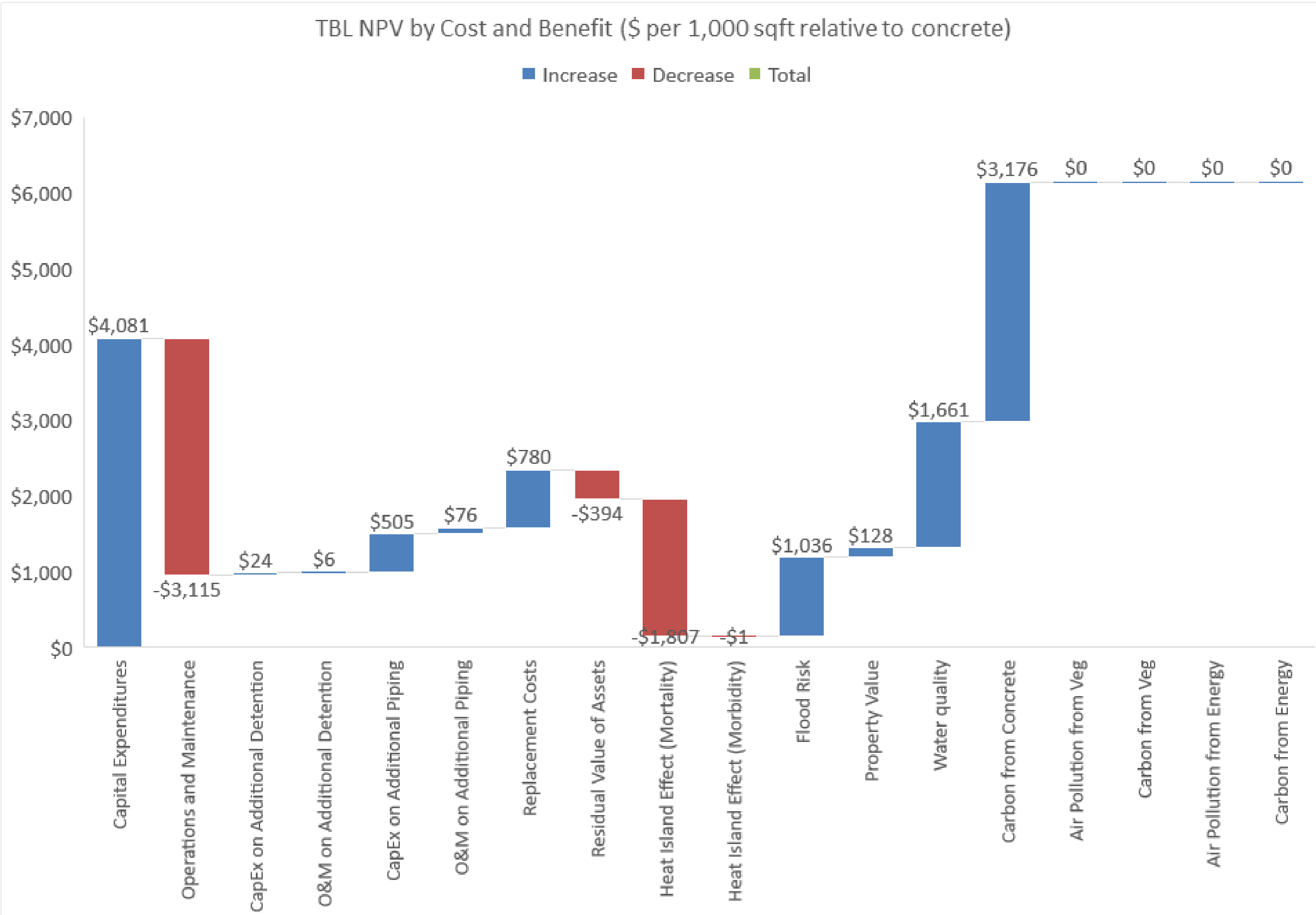

Figure 17: Breakdown of TBL NPV for Infiltration Trenches

Table 16: Infiltration Trench Relative Results Compared to Concrete with 95% CI ($/1,000 sq ft

Impact Type	Cost/Benefit	Mean Value	95% Confidence Interval		
Financial	Capital Expenditures	**$4,081**	$1,471	to	$6,056
Financial	Operations and Maintenance	**-$3,115**	-$3,115	to	-$3,115
Financial	CapEx on Additional Detention	**$24**	$9	to	$39
Financial	O&M on Additional Detention	**$6**	$0	to	$11
Financial	CapEx on Additional Piping	**$505**	$403	to	$642
Financial	O&M on Additional Piping	**$76**	$45	to	$110
Financial	Replacement Costs	**$780**	-$846	to	$2,859
Financial	Residual Value of Assets	**-$394**	-$868	to	$45
Social	Heat Island Effect (Mortality)	**-$1,807**	-$2,387	to	-$1,258
Social	Heat Island Effect (Morbidity)	**-$1**	-$3	to	$0
Social	Flood Risk	**$1,036**	$1,036	to	$1,036
Social	Property Value	**$128**	$81	to	$175
Environmental	Water quality	**$1,661**	$280	to	$3,444
Environmental	Carbon Emissions from Concrete	**$3,176**	$1,294	to	$5,771
Environmental	Air Pollution Reduced by Vegetation	**$0**	$0	to	$0
Environmental	Carbon Reduction by Vegetation	**$0**	$0	to	$0
Environmental	Air Pollution Reduced by Energy Use	**$0**	$0	to	$0
Environmental	Carbon Reduction by Energy Use	**$0**	$0	to	$0
Total	**Triple Bottom Line NPV**	**$6,155**	-$2,601	to	$15,815

3.6 Pervious Pavers

Pervious pavers generate an estimated -$5,400 (95% confidence interval of -$21,411 to $12,068) in triple bottom line net present value over a 50-year time horizon relative to Concrete, with -$11,100 created through financial impacts, $600 through social impacts, and $5,100 through environmental benefits.

Figure 18 shows a waterfall chart of the breakdown of these values. On the chart, blue represents value being created, whereas red represents a cost, relative to concrete. We can see that Pervious pavers have a much higher CapEx and replacement cost than Concrete. Varying amounts of value are created across the social and environmental spectrum of impacts, with the most significant being flood risk ($500), water quality ($1,900), and avoided carbon emissions from concrete use ($3,200).

The 95% confidence intervals shown in Table 17 allow us to see the uncertainty in some of these figures. There is a large spread in CapEx (-$11,670 to -$2,323), as well as water quality ($323 to $3,963), and when all impacts have been assessed it creates a large spread in overall TBL-NPV of -$21,411 to $12,068, indicating that there is a fair possibility of either a positive or negative TBL-NPV compared to Concrete.

Financial	Social	Environmental
-$11,067	$555	$5,088
Triple Bottom Line NPV		**-$5,424**

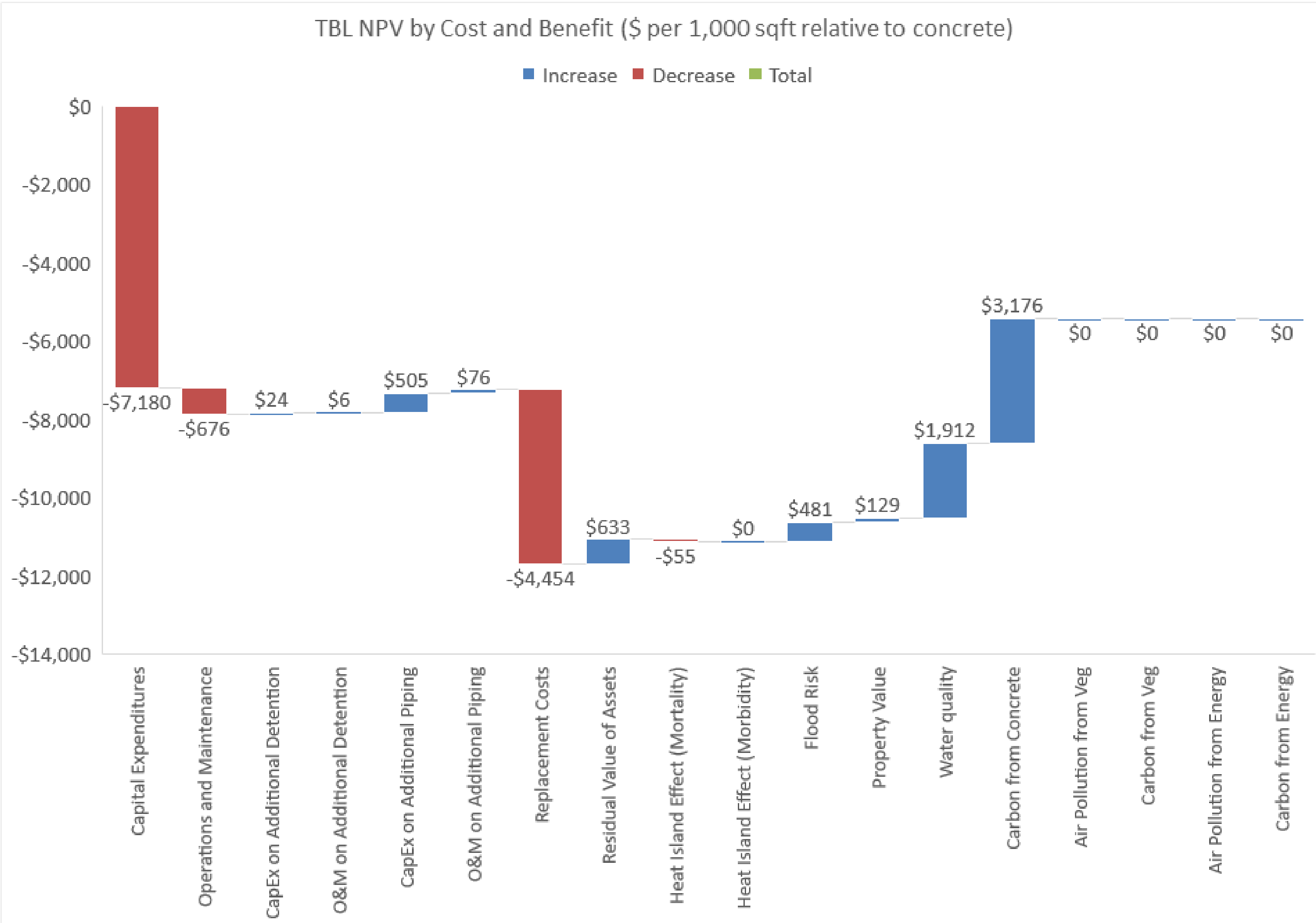

Figure 18: Breakdown of TBL NPV for Pervious Pavers

Table 17: Pervious Pavers Relative Results Compared to Concrete with 95% CI ($/1,000 sq ft

Impact Type	Cost/Benefit	Mean Value	95% Confidence Interval		
Financial	Capital Expenditures	**-$7,180**	-$11,670	to	-$2,323
Financial	Operations and Maintenance	**-$676**	-$1,019	to	-$381
Financial	CapEx on Additional Detention	**$24**	$9	to	$39
Financial	O&M on Additional Detention	**$6**	$0	to	$11
Financial	CapEx on Additional Piping	**$505**	$403	to	$642
Financial	O&M on Additional Piping	**$76**	$45	to	$110
Financial	Replacement Costs	**-$4,454**	-$9,355	to	-$157
Financial	Residual Value of Assets	**$633**	-$832	to	$2,671
Social	Heat Island Effect (Mortality)	**-$55**	-$1,167	to	$1,057
Social	Heat Island Effect (Morbidity)	**$0**	-$3	to	$4
Social	Flood Risk	**$481**	$481	to	$481
Social	Property Value	**$129**	$82	to	$181
Environmental	Water quality	**$1,912**	$323	to	$3,963
Environmental	Carbon Emissions from Concrete	**$3,176**	$1,294	to	$5,771
Environmental	Air Pollution Reduced by Vegetation	**$0**	$0	to	$0
Environmental	Carbon Reduction by Vegetation	**$0**	$0	to	$0
Environmental	Air Pollution Reduced by Energy Use	**$0**	$0	to	$0
Environmental	Carbon Reduction by Energy Use	**$0**	$0	to	$0
Total	**Triple Bottom Line NPV**	**-$5,424**	-$21,411	to	$12,068

3.7 Porous Concrete

Porous concrete generates an estimated $2,700 (95% confidence interval of -$8,647 to $14,938) in triple bottom line net present value over a 50-year time horizon relative to Concrete, with -$3,200 created through financial impacts, $800 through social impacts, and $5,100 through environmental benefits.

Figure 19 shows a waterfall chart of the breakdown of these values. On the chart, blue represents value being created, whereas red represents a cost, relative to concrete. We can see that Porous concrete has a much higher CapEx and replacement cost than Concrete. Varying amounts of value are created across the social and environmental spectrum of impacts, with the most significant being flood risk ($500), water quality ($1,900), and avoided carbon emissions from concrete use ($3,200).

The 95% confidence intervals shown in Table 18 allow us to see the uncertainty in some of these figures. There is a large spread in CapEx (-$4,358 to $152), replacement cost (-$4,079 to $1,262), as well as water quality ($323 to $3,963). When all impacts have been assessed it creates a large spread in overall TBL-NPV of -$8,647 to $14,938, indicating that there is a fair possibility of either a positive or negative TBL-NPV compared to Concrete.

Financial	Social	Environmental
-$3,211	$814	$5,088
Triple Bottom Line NPV		**$2,691**

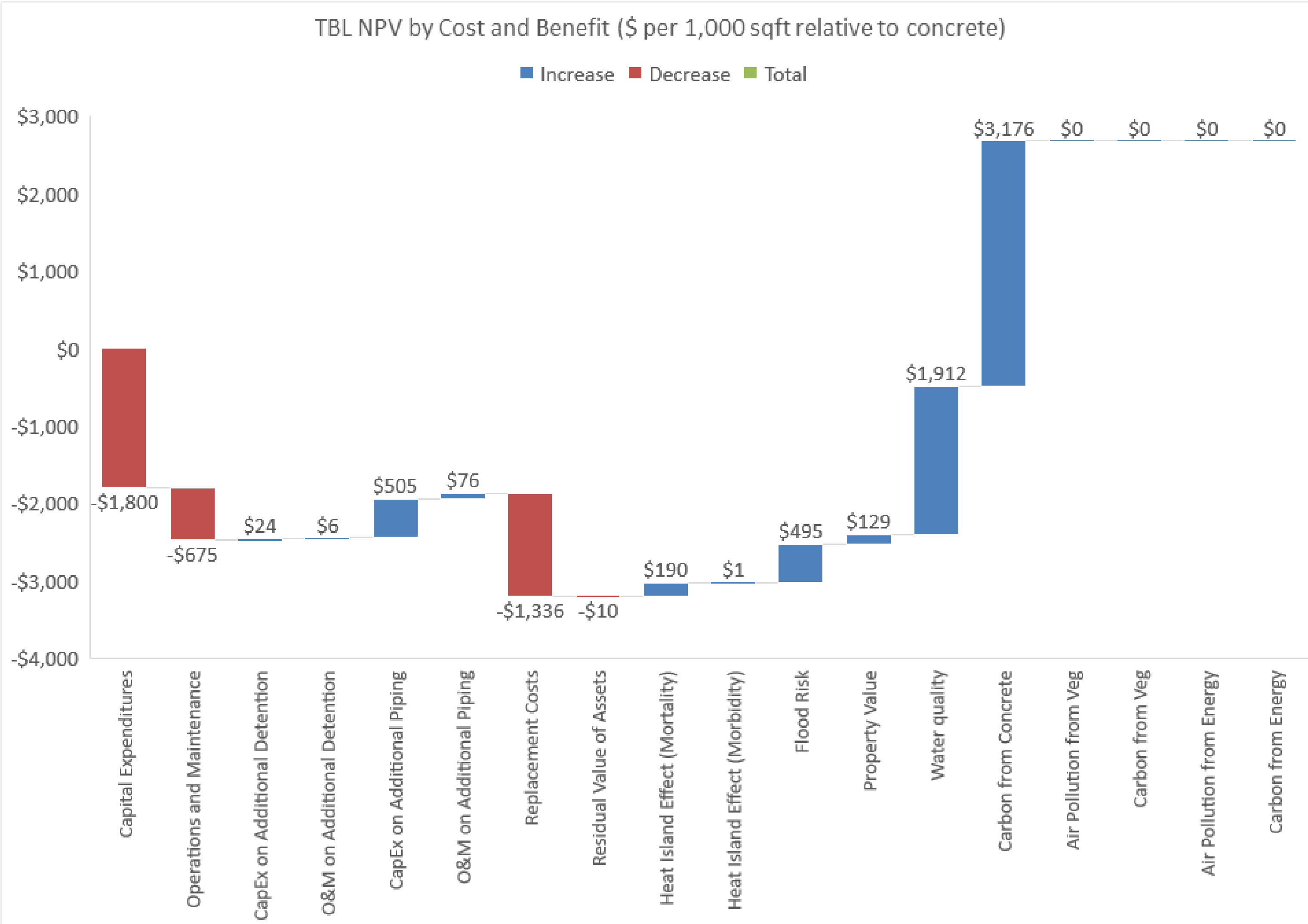

Figure 19: Breakdown of TBL NPV for Porous Concrete

Table 18: Porous Concrete Relative Results Compared to Concrete with 95% CI ($/1,000 sq ft

Impact Type	Cost/Benefit	Mean Value	95% Confidence Interval		
Financial	Capital Expenditures	**-$1,800**	-$4,358	to	$152
Financial	Operations and Maintenance	**-$675**	-$1,015	to	-$386
Financial	CapEx on Additional Detention	**$24**	$9	to	$39
Financial	O&M on Additional Detention	**$6**	$0	to	$11
Financial	CapEx on Additional Piping	**$505**	$403	to	$642
Financial	O&M on Additional Piping	**$76**	$45	to	$110
Financial	Replacement Costs	**-$1,336**	-$4,079	to	$1,262
Financial	Residual Value of Assets	**-$10**	-$845	to	$1,313
Social	Heat Island Effect (Mortality)	**$190**	-$997	to	$1,380
Social	Heat Island Effect (Morbidity)	**$1**	-$3	to	$4
Social	Flood Risk	**$495**	$495	to	$495
Social	Property Value	**$129**	$81	to	$180
Environmental	Water quality	**$1,912**	$323	to	$3,963
Environmental	Carbon Emissions from Concrete	**$3,176**	$1,294	to	$5,771
Environmental	Air Pollution Reduced by Vegetation	**$0**	$0	to	$0
Environmental	Carbon Reduction by Vegetation	**$0**	$0	to	$0
Environmental	Air Pollution Reduced by Energy Use	**$0**	$0	to	$0
Environmental	Carbon Reduction by Energy Use	**$0**	$0	to	$0
Total	**Triple Bottom Line NPV**	**$2,691**	-$8,647	to	$14,938

3.8 Porous Asphalt

Porous asphalt generates an estimated $2,200 (95% confidence interval of -$9,949 to $15,908) in triple bottom line net present value over a 50-year time horizon relative to Concrete, with -$2,100 created through financial impacts, -$800 through social impacts, and $4,800 through environmental benefits.

Figure 20 shows a waterfall chart of the breakdown of these values. On the chart, blue represents value being created, whereas red represents a cost, relative to concrete. We can see that Porous asphalt has small CapEx and O&M incremental costs, while replacement cost is the main cost driver. Varying amounts of value (as well as dis-benefits) are created across the social and environmental spectrum of impacts, with the most significant being heat island effect (-$1,400), water quality ($1,900), and avoided carbon emissions from concrete use ($3,200).

The 95% confidence intervals shown in Table 19 allow us to see the uncertainty in some of these figures. There is a large spread in CapEx (-$3,762 to $2,915), replacement cost (-$4,857 to $1,668), as well as water quality ($323 to $3,963). When all impacts have been assessed it creates a large spread in overall TBL-NPV of -$9,949 to $15,908, indicating that there is a fair possibility of either a positive or negative TBL-NPV compared to Concrete.

Financial	Social	Environmental
-$2,136	-$790	$4,837
Triple Bottom Line NPV		**$2,162**

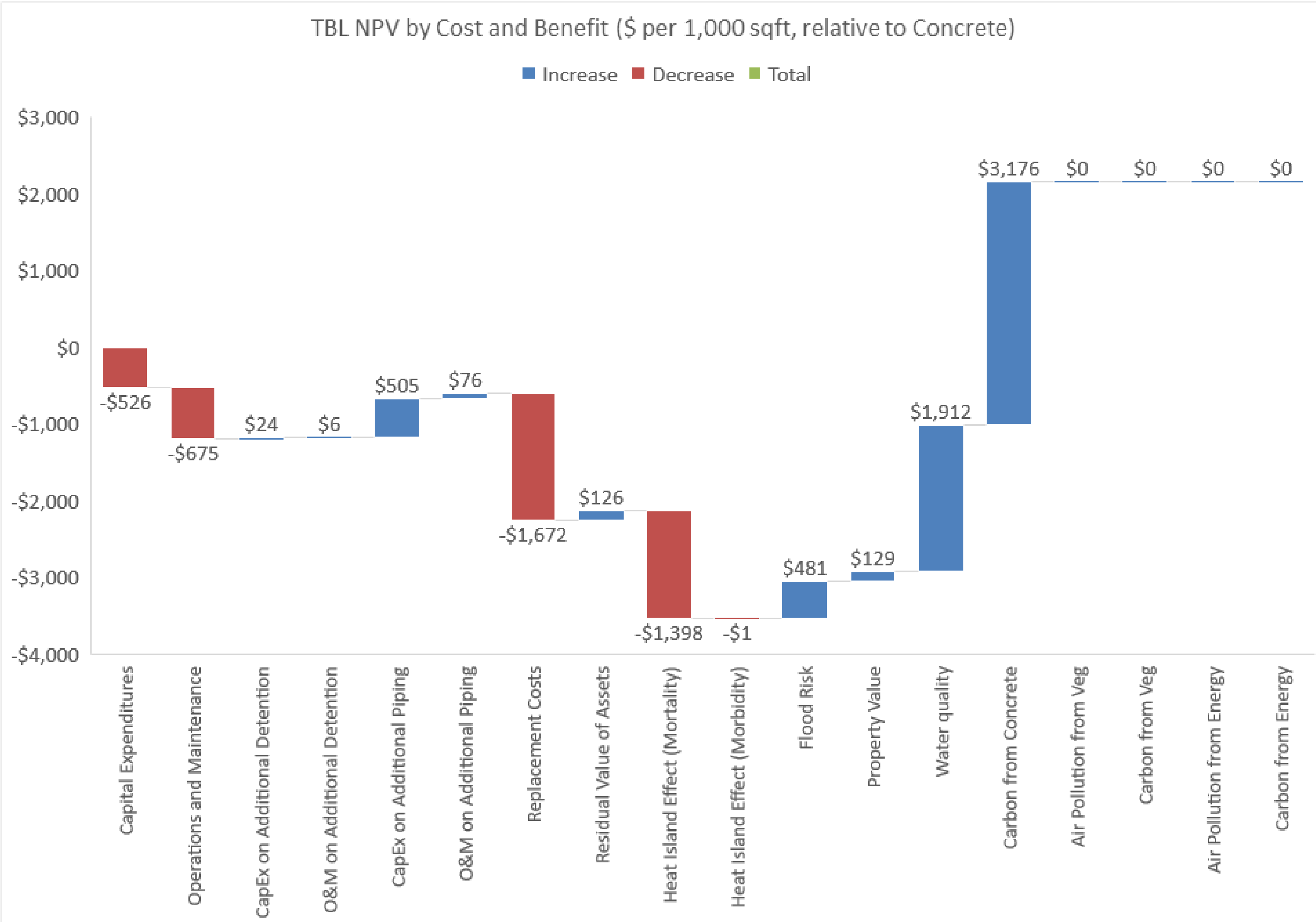

Figure 20: Breakdown of TBL NPV for Porous Asphalt

Table 19: Porous Asphalt Relative Results Compared to Concrete with 95% CI ($/1,000 sq ft)

Impact Type	Cost/Benefit	Mean Value	95% Confidence Interval		
Financial	Capital Expenditures	**-$526**	-$3,762	to	$2,915
Financial	Operations and Maintenance	**-$675**	-$1,015	to	-$386
Financial	CapEx on Additional Detention	**$24**	$9	to	$39
Financial	O&M on Additional Detention	**$6**	$0	to	$11
Financial	CapEx on Additional Piping	**$505**	$403	to	$642
Financial	O&M on Additional Piping	**$76**	$45	to	$110
Financial	Replacement Costs	**-$1,672**	-$4,857	to	$1,668
Financial	Residual Value of Assets	**$126**	-$845	to	$1,233
Social	Heat Island Effect (Mortality)	**-$1,398**	-$2,103	to	-$718
Social	Heat Island Effect (Morbidity)	**-$1**	-$4	to	$0
Social	Flood Risk	**$481**	$481	to	$481
Social	Property Value	**$129**	$82	to	$178
Environmental	Water quality	**$1,912**	$323	to	$3,963
Environmental	Carbon Emissions from Concrete	**$3,176**	$1,294	to	$5,771
Environmental	Air Pollution Reduced by Vegetation	**$0**	$0	to	$0
Environmental	Carbon Reduction by Vegetation	**$0**	$0	to	$0
Environmental	Air Pollution Reduced by Energy Use	**$0**	$0	to	$0
Environmental	Carbon Reduction by Energy Use	**$0**	$0	to	$0
Total	**Triple Bottom Line NPV**	**$2,162**	-$9,949	to	$15,908

4 Project Description (Case Study Sites)

This section describes the three case study sites that are assessed in this report, as well as outlines some of the more detailed design assumptions used in order to generate results within Autocase.

4.1 Sites to be Analyzed

The case study sites analyzed as part of this assessment are:

1. Primera Iglesia is located at 701 S. 1st Street, Phoenix, Arizona. The project installation date was November 2011 and included 15 new trees requiring no supplemental irrigation after the vegetation was established, 4,500 sq ft bioretention basin/rain garden, and curb cuts and cores. The project provided the first Phoenix area GI/LID site demonstration.
2. Glendale Community Center is located at 14075 N. 59th Avenue, Glendale, Arizona. The project installation date was March 2016 and included 8 new trees, two bioretention basins/rain gardens totalling 6,000 sq ft, which is expected to harvest 10,000 gallons of rainwater per year, and curb cuts.
3. A combined project encompassing Central Station, Civic Space Park, and Taylor Mall includes a transit center, public park, and pedestrian improvements generally located around 444 N. Central Avenue in Phoenix. The traditional features include landscaping and one new retention basin[2] equalling 0.33 acres and one existing retention basin equalling 0.147 acres. GI/LID features include 680 shrubs, 52,000 sq ft of pervious pavers, 13,000 sq ft of vegetated swales with trees, 1,600 sq ft of tree planters, 30,000 sq ft of porous concrete, 243 new trees, and one underground stormwater storage cistern[3] with a capacity of 9,600 cf.

Each of these were then compared against a base case to assess their *incremental* – or *relative* impact.

For Primera Iglesia and Glendale Community Center, the previously existing land cover was used as the base case because both locations were previously developed with no anticipated changes except the GI/LID projects. Therefore, the condition without the GI/LID projects would have remained without alteration. This previously existing land cover at both locations consisted of rocks and compacted, un-vegetated dirt surface. This land cover is not an automated feature type in Autocase, however after speaking to WMG and City staff, it was deemed that the best comparison in Autocase for the existing land cover type was asphalt due to the poor infiltration, water runoff, and heat island impact. Therefore, for Primera and Glendale Community Center, 'Asphalt' was used within Autocase as the base case from which to compare the design. A 20,000 square foot watershed area was included for the case study and comparison base design at Primera Iglesia, and a 25,000 square foot watershed area for both design scenarios at Glendale, in order to represent the surface area that would generate runoff flowing in to each project.

For the Central Station/Civic Space Park/Taylor Mall project, the base case used was concrete. Although the previously existing condition was asphalt parking lot, this case study used an alternate development land cover instead. If GI/LID had not been included as part of the redevelopment, the redevelopment would still have occurred. Therefore, using the previously existing condition as we did for the other two case studies would not have been appropriate. Most the area with GI/LID features constructed would

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[2] A storage area to manage stormwater runoff to prevent flooding and downstream erosion.

[3] A rigid device of metal, plastic, or other solid material that captures and stores water from an impervious surface.

likely have been concrete (e.g., pervious pavers and porous concrete at Civic Space Park would likely have been an impervious concrete plaza) and asphalt (e.g., Taylor Mall parking spaces); therefore, the base case selected is a concrete feature equal to the size of the LID features. The base case design also included the new and existing retention basins (0.33 acres and 0.147 acres, respectively), as well as 118 trees to conform to local requirements for retention and tree spacing. A 10.3-acre feature watershed area was included in each analysis to represent the surface area that would generate runoff flowing into the project.

4.2 Project Inputs

This and all further subsections in Section 3 provide information on the specific inputs used in Autocase for each case study and its associated base case comparison design. The specific inputs for the case studies are based on the actual design plans, Google Earth reviews of the finished project, construction cost documents, which are supplemented by SUSTAIN database and the National Stormwater Management Calculator.

4.2.1 Primera Iglesia

4.2.1.1 Base Case

This section outlines the inputs used in Autocase for the base case for Primera Iglesia.

Figure 21: Primera Iglesia (Before)
Source: Watershed Management Group

Table 20: Primera Iglesia Base Case Inputs

	Unit	Expected Value
Name of feature	-	Asphalt
Area	Sq ft	4,480
New or existing?	-	Existing

Notes:

- A feature watershed of 20,000 sq ft was also included as part of the base case.

4.2.1.2 LID Design

This section outlines the inputs used in Autocase for the LID design for Primera Iglesia.

Figure 22: Primera Iglesia (After)
Source: Watershed Management Group

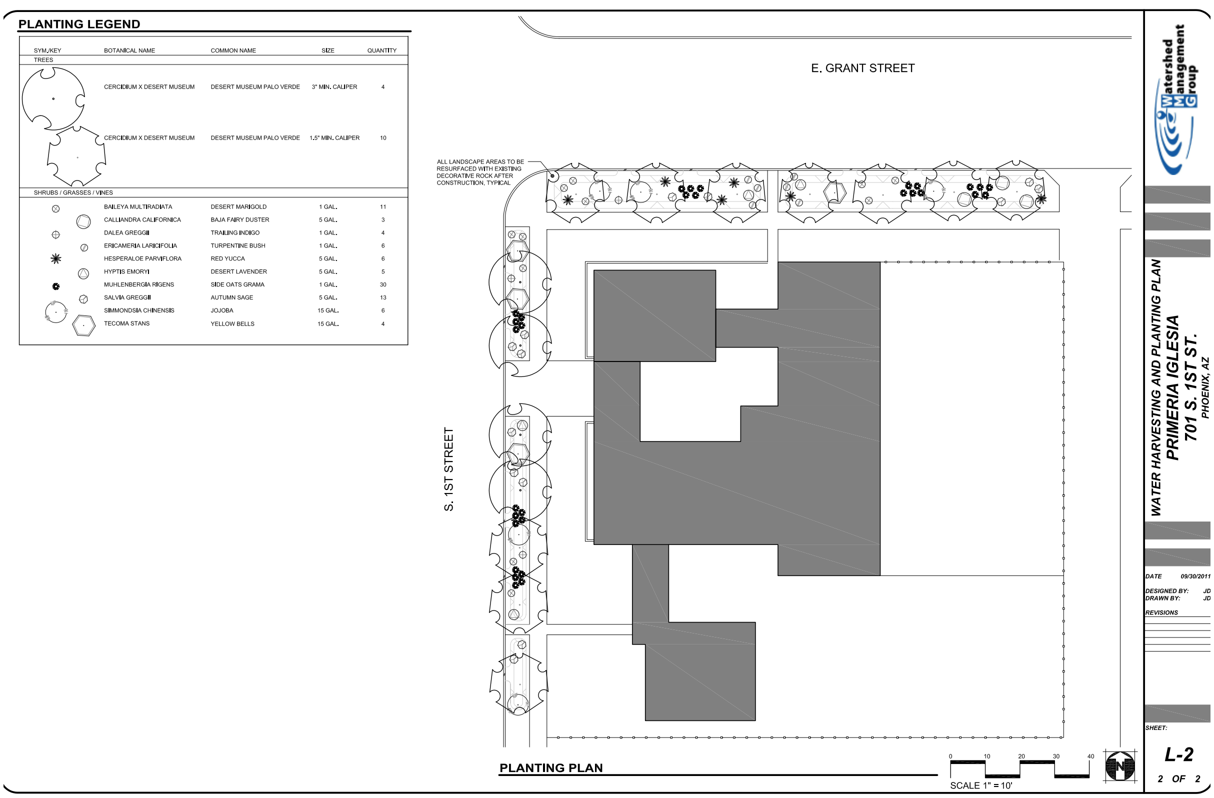

Figure 23: Primera Iglesia Site Plans
Source: Watershed Management Group

Table 21: Primera Iglesia Bioretention Basin Inputs

	Unit	Expected Value
Name of feature		Bioretention/Rain garden
Area	sq ft	4,480
New or existing?		New
Maximum Ponding/Treatment Depth	Inches	6
Depth of Coverage Materials	Inches	3
Percent Empty Space in Material	%	40
Rate of Gray Discharge from Outlet of Feature	-	-
Does this feature allow for infiltration?	Yes/No	Yes
Trees Planted	#	15
Shrubs planted	#	125
Shrubs Average Expected Lifespan	Year	10
Shrubs Max Expected Lifespan	Year	20
Soil type		B
Maximum Surface Infiltration Rate	Inches per hour	4.5
Minimum Surface Infiltration Rate	Inches per hour	0.25
Infiltration Rate Reduction Factor	per hour	1
Capital Expenditure	$	$8,785
Annual O&M	$	$542 (Low = $433, High = $677)

Notes:

- CapEx come from WMG site costs for Primera Iglesia
- A feature watershed of 20,000 sq ft was also included as part of the design case.
- O&M costs are from Watershed Management Group estimates based on $120/1,000 sq ft at a rate of $75/hr.

4.2.2 Glendale Community Center

4.2.2.1 Base Case

This section outlines the inputs used in Autocase for the base case for Glendale Community Center.

Figure 24: Glendale Community Center (Before)
Source: Watershed Management Group

Table 22: Glendale Community Center Base Case Inputs

	Unit	Design case
Name of feature	-	Asphalt
Area	Sq ft	6,000
New or existing?	-	Existing

Notes:

- A feature watershed of 25,000 sq ft was also included as part of the base case.
- Asphalt was chosen as the Base Case feature type in Autocase, due to the porosity and solar absorption properties of the existing features.

4.2.2.2 LID Design

This section outlines the inputs used in Autocase for the LID design for Glendale Community Center.

SYM./KEY	BOTANICAL NAME	COMMON NAME	SIZE	QUANITITY	EMITTER (PER PLANT)	E. SIZE (GPH)	ZONE
TREES							
	Chilopsis linearis	Desert Willow	15 GAL.	8	4	2	TREE
SHRUBS / GRASSES							
	Hyptis emoryi	Desert Lavender	5 GAL.	3	2	1	SHRUB
	Simmondsia chinensis	Jojoba	5 GAL.	3	2	1	SHRUB
	Larrea tridentata	Creosote	5 GAL.	3	2	1	SHRUB
	Calliandra eriophylla	Pink Fairy Duster	5 GAL.	13	2	1	SHRUB
	Justicia californica	Chuparosa	5 GAL.	12	2	1	SHRUB
	Viguiera parishii	Goldeneye	5 GAL.	15	2	1	SHRUB
	Encelia farinosa	Brittlebush	1 GAL.	3	2	1	SHRUB
	Baileya multiradiata	Desert Marigold	1 GAL.	15	2	1	SHRUB
	Melampodium leucanthum	Blackfoot Daisy	1 GAL.	15	2	1	SHRUB
	Asclepias subulata	Desert Milkweed	5 GAL.	9	2	1	SHRUB
	Penstemon eatoni	Firecracker Penstemon	1 GAL.	6	2	1	SHRUB
	Bouteloua curtipendula	Sideoats Grama	1 GAL.	21	2	1	SHRUB
SURFACE MATERIALS							
	Boulders Surface Select	2 TON					
	Rip-Rap 3"-12" (Palomino Gold)	9 TON					
Not Shown	Decorative Gravel (Palomino Gold)	32 TON					

NOTES:

EXISTING DECORATIVE ROCK, RIVER ROCK, AND LANDSCAPE DEBRIS TO BE REMOVED FROM SITE.

EXISTING VEGETATION TO BE REMOVED FROM SITE IF NOT MARKED TO REMAIN.

EXCAVATION OF RAINWATER HARVESTING FEATURE TO BE MININAL AS SITE IS LOCATED IN EXISTING RETENTION BASIN.

LANDSCAPE AREA ADJACENT TO WALKWAYS TO BE GRADED 3" BELOW HARDSCAPE TOP SURFACE TO ALLOW FOR 2" OF SURFACE COVER.

EXCAVATED SOIL NOT USED TO CREATE BERMS TO BE REMOVED FROM SITE.

3"-12" RIP-RAP TO BE USED FOR ERROSION CONTROL IN AREAS AS SHOWN ON DRAWING.

LANDSCAPE AREA TO BE RESURFACED WITH 2" LAYER OF DECORATIVE GRAVEL AFTER CONSTRUCTION.

TREES TO BE PLANTED A MINIMUM OF 20' AWAY FROM ANY BUILDING.

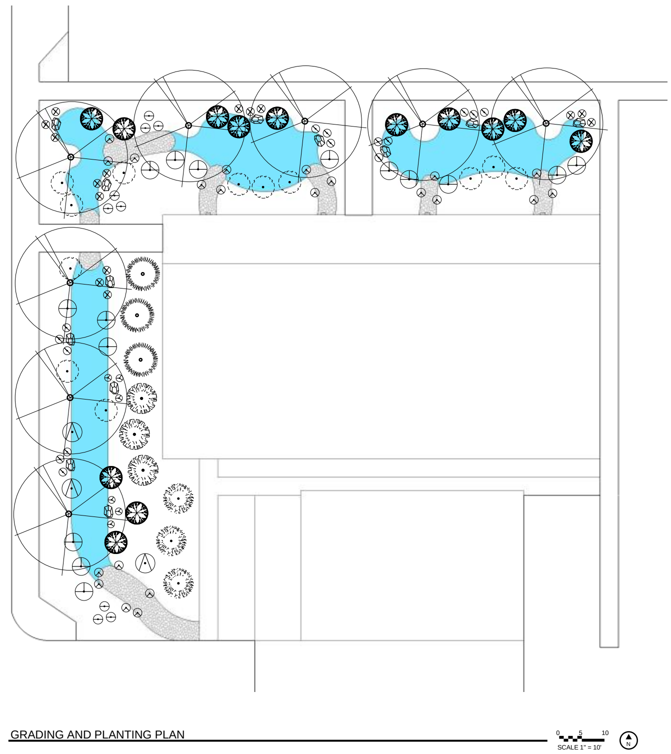

Figure 25: Glendale Site Plans (draft design)
Source: Watershed Management Group

Figure 26: Glendale Community Center (After)
Source: Watershed Management Group

Table 23: Glendale Community Center Bioretention Basin Inputs

	Unit	Design case
Name of feature		Bioretention/Rain garden
Area	sq ft	6,000
New or existing?		New
Maximum Ponding/Treatment Depth	Inches	6
Depth of Coverage Materials	Inches	3
Percent Empty Space in Material	%	40
Rate of Gray Discharge from Outlet of Feature	-	-
Does this feature allow for infiltration?	Yes/No	Yes
Trees Planted	#	8
Shrubs planted	#	128
Shrubs Average Expected Lifespan	Year	10
Shrubs Max Expected Lifespan	Year	20
Soil type		B
Maximum Surface Infiltration Rate	Inches per hour	4.5
Minimum Surface Infiltration Rate	Inches per hour	0.25
Infiltration Rate Reduction Factor	per hour	1
Capital Expenditure	$	$14,100
Annual O&M	$	$726 (Low = $581, High = $907)

Notes:

- A feature watershed of 25,000 sq ft was also included as part of the design case.
- CapEx and O&M costs come from WMG site costs for Primera iglesia.
- O&M costs are from Watershed Management Group estimates based on $120/1,000 sq ft at a rate of $75/hr.
- Numbers here differ to the design schematic as this was based on as-built measurements and costs.

4.2.3 Central Station/Civic Space Park/Taylor Mall

4.2.3.1 Base Case

This section outlines the inputs used in Autocase for the base case for Central Station/Civic Space Park/Taylor Mall.

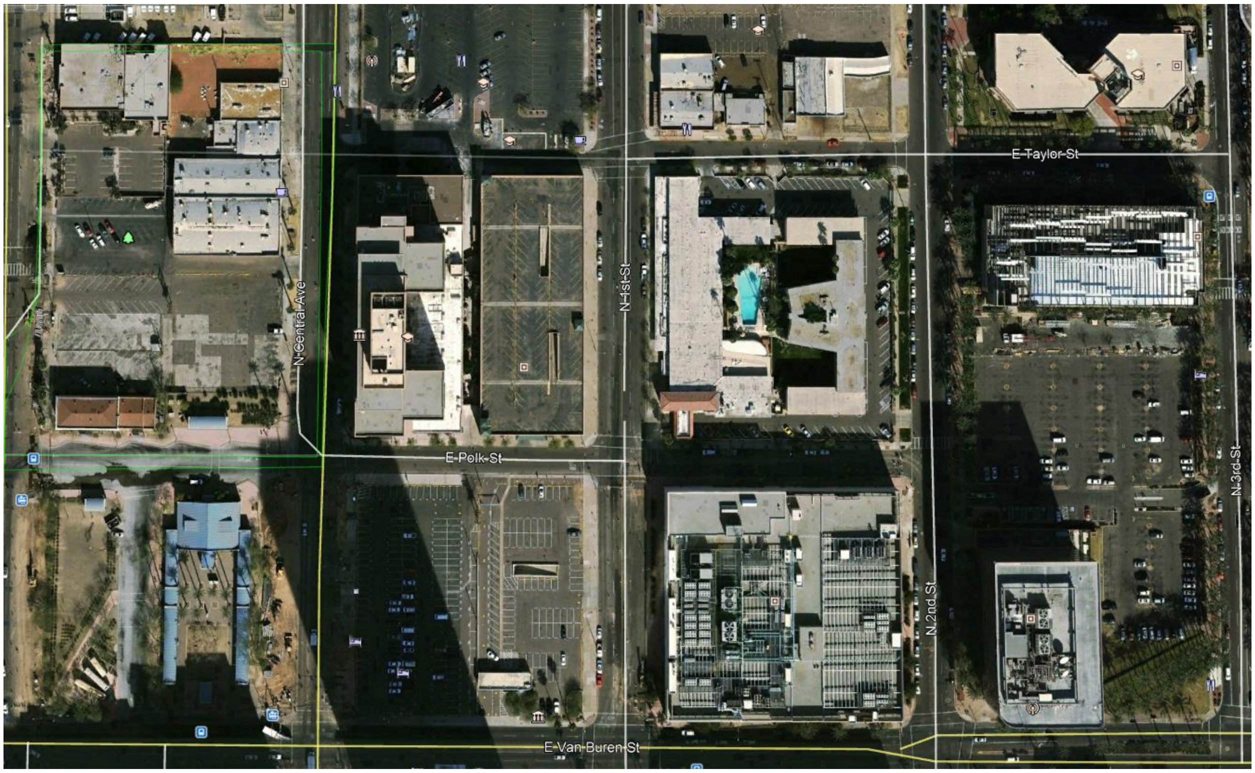

Figure 27: Central Station/Civic Space Park/Taylor Mall project area (before, circa 2005)

Table 24: Central/Civic/Taylor Base Case Inputs: Trees

	Unit	Expected Value
Name of feature		Additional Trees
New or existing?		New
Number of new trees being planted	#	118
Soil type		B
Maximum Surface Infiltration Rate	Inches per hour	4.5
Minimum Surface Infiltration Rate	Inches per hour	0.25
Infiltration Rate Reduction Factor	per hour	1
Capital Expenditure	$	$69,738 (Low = $18,880, High = $87,173)
Annual O&M	$	$1,841 (Low = $1,381, High = $2,301)

Notes:

- The base case also includes a feature watershed of 10.3 acres.
- CapEx = $591.00 per tree taken from Taylor Mall 100% Plan Model. Low = SUSTAIN, High = Local +25%
- O&M = $15.60 per tree. Watershed Management Group based $160/1,000 sq ft at a rate of $100 per hour (instead of $75/hr, as trees are costlier) and assuming each tree is 9 square meters. Low/High = +/- 25%.

Table 25: Central/Civic/Taylor Base Case Inputs: Concrete

	Unit	Expected Value
Name of feature		Concrete
Area	Acre	2.21
New or existing?		New
Depth of coverage material	Inches	3
Capital expenditure	$	$554,622 (Low = $434,052, High = $675,192)
Annual O&M	$	$0

Notes:

- CapEx and O&M source are City of Phoenix Streets department for per-1,000 sq ft cost estimates.

Table 26: Central/Civic/Taylor Base Case Inputs: New Retention Basin

	Unit	Design case
Name of feature		New Retention basin
Area	Acre	0.33
New or existing?		New
Maximum Ponding/Treatment Depth	Inches	12
Rate of Gray Discharge from Outlet of Feature	-	-
Minimum Permanent Depth	Inches	12
Capital Expenditure	$	$166,029 (Low = $61,237, High = $326,452)
Annual O&M	$	$431 (Low = $216, High = $862)

Notes:

- CapEx = $4,260 per cu ft and includes excavation and landscaping.
- CapEx and O&M are from the National Stormwater Management Calculator.

Table 27: Central/Civic/Taylor Base Case Inputs: Existing Retention Basin

	Uni	Expected Value
Name of feature		Existing Retention basin
Area	Acre	0.145
New or existing?		Existing
Maximum Ponding/Treatment Depth	Inches	36
Rate of Gray Discharge from Outlet of Feature	-	-
Minimum Permanent Depth	Inches	36

Notes:

- This already exists on the site so there is no incremental cost with this.

4.2.3.2 LID Design

This section outlines the inputs used in Autocase for the LID design for Central Station/Civic Space Park/Taylor Mall.

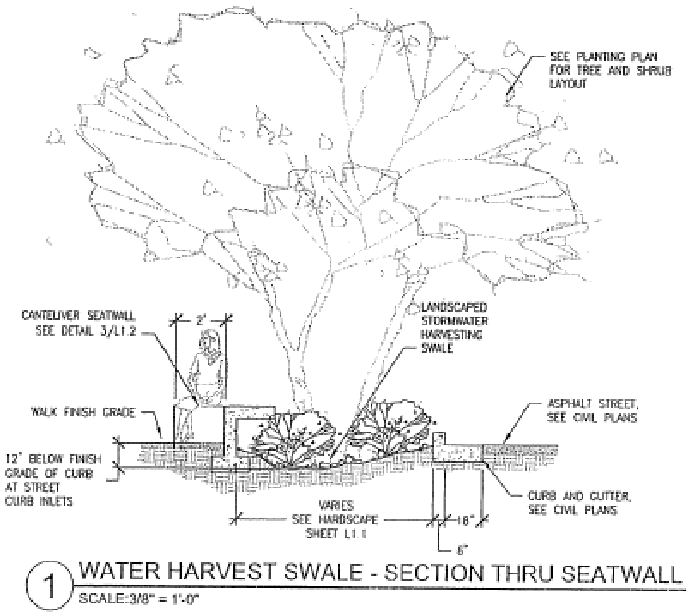

Figure 28: Taylor Mall Site Plan

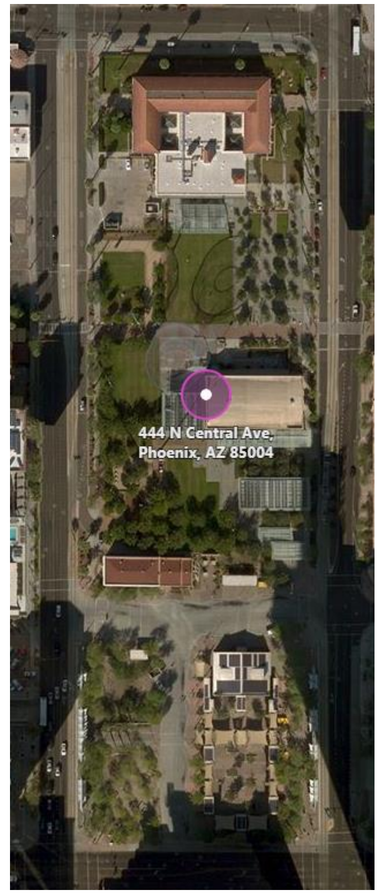

Figure 29: Central Station/Civic Space (after)

Figure 30: Taylor Mall (After)

Table 28: Central/Civic/Taylor GI/LID Inputs: Shrubs

	Unit	Expected Value
Name of feature		Shrubs
New or existing?		New
Number of new shrubs being planted	#	680
Area of new shrubs being planted	Acre	-
Soil type	Choice	B
Shrubs Average Expected Lifespan	Year	8.5
Shrubs Max Expected Lifespan	Year	10
Soil type		B
Maximum Surface Infiltration Rate	Inches per hour	4.5
Minimum Surface Infiltration Rate	Inches per hour	0.25
Infiltration Rate Reduction Factor	per hour	1
Capital Expenditure	$	$9,280 (Low = $4,640, High = $15,081)
Annual O&M	$	-

Notes:
- O&M included as part of O&M costs of other features.

Table 29: Central/Civic/Taylor GI/LID Inputs: Pervious Pavers

	Unit	Expected Value
Name of feature		Pervious Paver
Area	Sq ft	51,960
New or existing?		New
Depth of Coverage Materials	Inches	3.5
Percent Empty Space in Material	%	20
Rate of Gray Discharge from Outlet of Feature	-	-
Soil type		B
Maximum Surface Infiltration Rate	Inches per hour	4.5
Minimum Surface Infiltration Rate	Inches per hour	0.25
Infiltration Rate Reduction Factor	per hour	1
Capital Expenditure	$	$673,921 (Low = $391,778, High =$924,888)
Annual O&M	$	$1,253 (Low = $626, High = $2,505)

Notes:
- CapEx of $12.97 per 1 sq ft was found using Taylor Mall 100% Plan Cost Model. Low and High from SUSTAIN
- O&M costs are based off $12/1,000 sq ft for power washing costs for porous concrete at Glendale Park and Ride for FY 2017. Low = 1 wash, Expected = 2 washes, High = 4 washes.

Table 30: Central/Civic/Taylor GI/LID Inputs: Swale

	Unit	Expected Value
Name of feature		Swale
Area	Sq ft	13,070
New or existing?		New
Maximum Ponding/Treatment Depth	Inches	12
Channel Bank Height	Inches	12
Soil type		B
Maximum Surface Infiltration Rate	Inches per hour	4.5
Minimum Surface Infiltration Rate	Inches per hour	0.25
Infiltration Rate Reduction Factor	per hour	1
Capital Expenditure	$	$72,238 (Low = $14,686, High = $148,455
Annual O&M	$	$1,581 (Low = $1,265, High = $1,976)

Notes:

- CapEx: Swale cost taken from 2nd-3rd st site plans, which was 1,717 sq ft and then scaled to 13,070 sq ft to encompass all swales constructed as part of this project.
- CapEx: Low = Includes 1 tree, 8 shrubs, 8 feet of curb cuts per 1,000 sq ft. Does not include concrete removal or the concrete single curb. Expected = Does not include concrete removal. Includes concrete single curb, 2 trees, 16 shrubs, 16 feet of curb cuts per 1,000 sq ft. High = Includes concrete removal, concrete single curb, 3 trees, 26 shrubs, 24 feet of curb cuts (8 openings, 3' each) per 1,000 sq ft.
- O&M: WMG estimates at $120/1,000 sq ft at $75 per hour labor cost.

Table 31: Central/Civic/Taylor GI/LID Inputs: Tree Planter

	Unit	Expected Value
Name of feature		Tree planter
Area	Sq ft	1,600
New or existing?		New
Storage volume	Cubic feet	2,925
Depth of Coverage Materials	Inches	12
Percent Empty Space in Material	%	30
Capital Expenditure	$	$12,800 (Low = $880, High = $39,200)
Annual O&M	$	$194 (Low = $155, High = $242

Notes:

- CapEx = Expected, Low, and High values from National Stormwater Management Calculator
- O&M: WMG estimates at $120/1,000 sq ft at $75 per hour labor cost.

Table 32: Central/Civic/Taylor GI/LID Inputs: Porous Concrete

	Unit	Design case
Name of feature		Porous concrete
Area	Sq ft	29,826
New or existing?		New
Depth of Coverage Materials	Inches	4
Percent Empty Space in Material	%	20
Rate of Gray Discharge from Outlet of Feature	-	0
Soil type		B
Maximum Surface Infiltration Rate	Inches per hour	4.5
Minimum Surface Infiltration Rate	Inches per hour	0.25
Infiltration Rate Reduction Factor	per hour	1
Capital Expenditure	$	$208,782 (Low = $190,000, High = $318,000)
Annual O&M	$	$719 (Low = $359, High = $1,438)

Notes:

- CapEx: Expected = Site specific cost from the line items taken from Central Station Upgrades. Low and High values taken from SUSTAIN.
- O&M costs are based off $12/1,000 sq ft for power washing costs for porous concrete at Glendale Park and Ride for FY 2017. Low = 1 wash per year, Expected = 2 times per year, High = 4 times per year.

Table 33: Central/Civic/Taylor GI/LID Inputs: Trees

	Unit	Expected Value
Name of feature		Additional Trees
New or existing?		New
Number of new trees being planted	#	243
Area of new trees being planted	Acre	-
Soil type		B
Maximum Surface Infiltration Rate	Inches per hour	4.5
Minimum Surface Infiltration Rate	Inches per hour	0.25
Infiltration Rate Reduction Factor	per hour	1
Capital Expenditure	$	$143,530 (Low = $38,858, High = $179,413)
Annual O&M	$	$3,798 (Low = $2,841, High = $4,763

Notes:

CapEx: $591.00 per tree. Mean amount per tree taken from Taylor Mall 100% Plan Model. Low = SUSTAIN, High = Local +25%

O&M: $15.60 per tree. Watershed Management Group at $100 per hour and assuming each tree is 9 square meters. Low/High = +/- 25%.

Table 34: Central/Civic/Taylor GI/LID Inputs: Underground Stormwater Storage

	Unit	Expected Value
Name of feature		Underground stormwater storage
Storage volume	Cubic feet	9,587
New or existing?		New
Surface Area Draining into feature	Acres	2.3
Expected outflow when filled	Cubic feet/hr	0
Capital expenditure	$	$11,550 (Low = $8,662, High = $14,437)
Annual O&M	$	$13 (Low = $5, High = $60)

Notes:

- CapEx: Site plans for Civic Space Park. High/Low = +/- 25%
- O&M: SUSTAIN

Table 35: Central/Civic/Taylor GI/LID Inputs: New Retention Basin

	Unit	Design case
Name of feature		Retention basin
Area	Acre	0.33
New or existing?		New
Maximum Ponding/Treatment Depth	Inches	12
Rate of Gray Discharge from Outlet of Feature	-	-
Minimum Permanent Depth	Inches	12
Capital Expenditure	$	$166,029 (Low = $61,237, High = $326,452)
Annual O&M	$	$431 (Low = $216, High = $862)

Notes:

- CapEx = $4,260 per cu ft and includes excavation and landscaping.
- CapEx and O&M are from the National Stormwater Management Calculator.

Table 36: Central/Civic/Taylor GI/LID Inputs: Existing Retention Basin

	Unit	Expected Value
Name of feature		Retention basin
Area	Acre	0.145
New or existing?		Existing
Maximum Ponding/Treatment Depth	Inches	36
Rate of Gray Discharge from Outlet of Feature	-	-
Minimum Permanent Depth	Inches	36

Notes:

- This already exists on the site so there is no incremental cost with this.

5 Triple Bottom Line Net Present Value Results (Case Study Sites)

This Section provides an overview of the results of the three case study sites. Dollar amounts reflect costs and benefits estimated for the full 50-year time horizon. The Central/Civic/Taylor inputs were based on design plans and cost estimates – not as-built or invoices, however feature sizes were verified by ground truthing. The tables and graphs that follow show the total cost of ownership of each site, along with the social and environmental benefits that are generated over the 50-year time horizon. Negative numbers represent a cost or disbenefit (financial, social, or environmental), whereas positive numbers illustrate a saving or benefit – the larger the number, the greater the cost or benefit.

5.1 Summary of Results

A summary of the financial, social, and environmental impacts for each case study site are given in Table 37. Results indicate that Primera Iglesia and Glendale Community Center each generate positive TBL-NPV ($54,600 and $67,500, respectively) over 50 years, while Central Station/Civic Space Park/Taylor Mall is estimated to have a negative TBL-NPV of around -$170,000.

We can see that each project generates large social and environmental benefits. Primera Iglesia creates around $65,000 and $15,000, respectively, Glendale Community Center creates $90,000 and $16,000, and Central/Civic/Taylor generates around $408,000 and $435,000 in social and environmental benefits.

It is important to remember that for Primera Iglesia and Glendale Community Center, the base case was a do-nothing (i.e. no cost) scenario; the land cover would have remained the same at no cost. If these sites were to have replaced their land cover with newly built non-GI/LID features, the financial results may have looked more favourable toward LID. The base case for Central/Civic/Taylor was new concrete i.e. new concrete would have been laid down instead of GI/LID. Despite this base case being new concrete (thus incurring a CapEx) and other required features, the financial cost of GI/LID on this project was still significantly higher.

Table 37: Summary of Triple Bottom Line Results Compared to Base Case

	Primera Iglesia	Glendale Community Center	Central/Civic/Taylor
Financial	-$26,286	-$38,455	-$1,014,293
Social	$65,879	$89,866	$408,123
Environmental	$15,019	$16,053	$435,336
Triple Bottom Line NPV	**$54,612**	**$67,464**	**-$170,834**

5.2 Detailed Results

Table 38 breaks down the results for the sites by each impact type. For a more detailed breakdown of the results, which include the 95% confidence intervals for each cost and benefit, please refer to the sections that follow. The purpose of this table is not to compare one site against another, given the different features implemented, their locations, and size of projects, but to help understand where value is being generated or lost for each project.

In terms of financial impacts, it is clear that CapEx is a large driver within all projects. However, O&M actually outweighs CapEx in Primera Iglesia and Glendale Community Center. Another key takeaway from this table is the replacement costs (see methodology section 8.3.1.3), which are significant cost factors – coming in at about half as much as CapEx. If these were to be lower in practice than the expected ones estimated here (perhaps due to good upkeep and maintenance), then the projects would look more favourable on a pure financial basis.

Socially, we see the biggest driver of benefits comes from heat island effect. Given future temperature predictions for Maricopa County under RCP8.5, even small reductions in temperature from shading and vegetation will generate significant heat risk mortality benefits. Flood risk attenuation is the second key driver for social impacts, arising from the improved infiltration resulting from GI/LID.

In terms of environmental factors, we can see that water quality benefits from reduced runoff create significant value. Avoided concrete use in the Central/Civic/Taylor site is also a key benefit driver. Finally, we can see that each site generates benefit from carbon emissions and air pollution due to vegetation and avoided energy use.

Table 38: TBL-NPV Results for Each Feature by Impact Type

Impact Type	Cost/Benefit	Primera Iglesia	Glendale Community Center	Central/ Civic/Taylor
Financial	Capital Expenditures	-$8,863	-$14,226	-$576,502
Financial	Operations and Maintenance	-$14,169	-$18,693	-$153,037
Financial	CapEx on Additional Detention	$36	$46	$0
Financial	O&M on Additional Detention	$9	$12	$0
Financial	CapEx on Additional Piping	$769	$973	$0
Financial	O&M on Additional Piping	$114	$144	$0
Financial	Replacement Costs	-$4,850	-$7,794	-$333,981
Financial	Residual Value of Assets	$669	$1,084	$49,228
Social	Heat Island Effect (Mortality)	$59,148	$78,232	$333,713
Social	Heat Island Effect (Morbidity)	$20	$9	$598
Social	Flood Risk	$5,260	$8,974	$65,457
Social	Property Value	$1,451	$2,650	$8,354
Environmental	Water quality	$5,444	$6,742	$92,319
Environmental	Carbon Emissions from Concrete	$0	$0	$281,536
Environmental	Air Pollution Reduced by Vegetation	$6,397	$6,974	$31,586
Environmental	Carbon Reduction by Vegetation	$469	$378	$3,114
Environmental	Air Pollution from Energy Use Reduction	$1,479	$1,106	$14,608
Environmental	Carbon Emissions from Energy Use Reduction	$1,230	$853	$12,173
Total:	**Triple Bottom Line NPV**	**$54,612**	**$67,464**	**-$170,834**

5.3 Primera Iglesia

Primera Iglesia has a TBL-NPV of $55,000 (95% confidence interval of $23,653 to $88,273) over 50 years and creates around $66,000 and $15,000 in social and environmental benefits, respectively. Diving deeper into the results, we see that O&M is the largest driver within the financial impacts at around -$14,000 over 50 years. However, in terms of social benefits, the tree coverage and LID features generate significant heat island reduction benefits ($59,000), and flood risk reduction ($5,300). There are positive environmental benefits, with around $5,400 through improved water quality, and $9,600 in reduced carbon emissions and air pollution through vegetation and avoided energy use.

Looking at the confidence intervals in Table 39, we can see that there is a fairly tight spread within the financial impacts, suggesting they have less uncertainty surrounding them. The most uncertainty is around heat island effect ($41,178 to $78,135) and water quality ($920 to $11,288). When all impacts have been assessed it creates a large spread in overall TBL-NPV of $23,653 to $88,273, but even the low estimate creates a positive TBL-NPV.

Financial	Social	Environmental
-$26,286	$65,879	$15,019
Triple Bottom Line NPV		**$54,612**

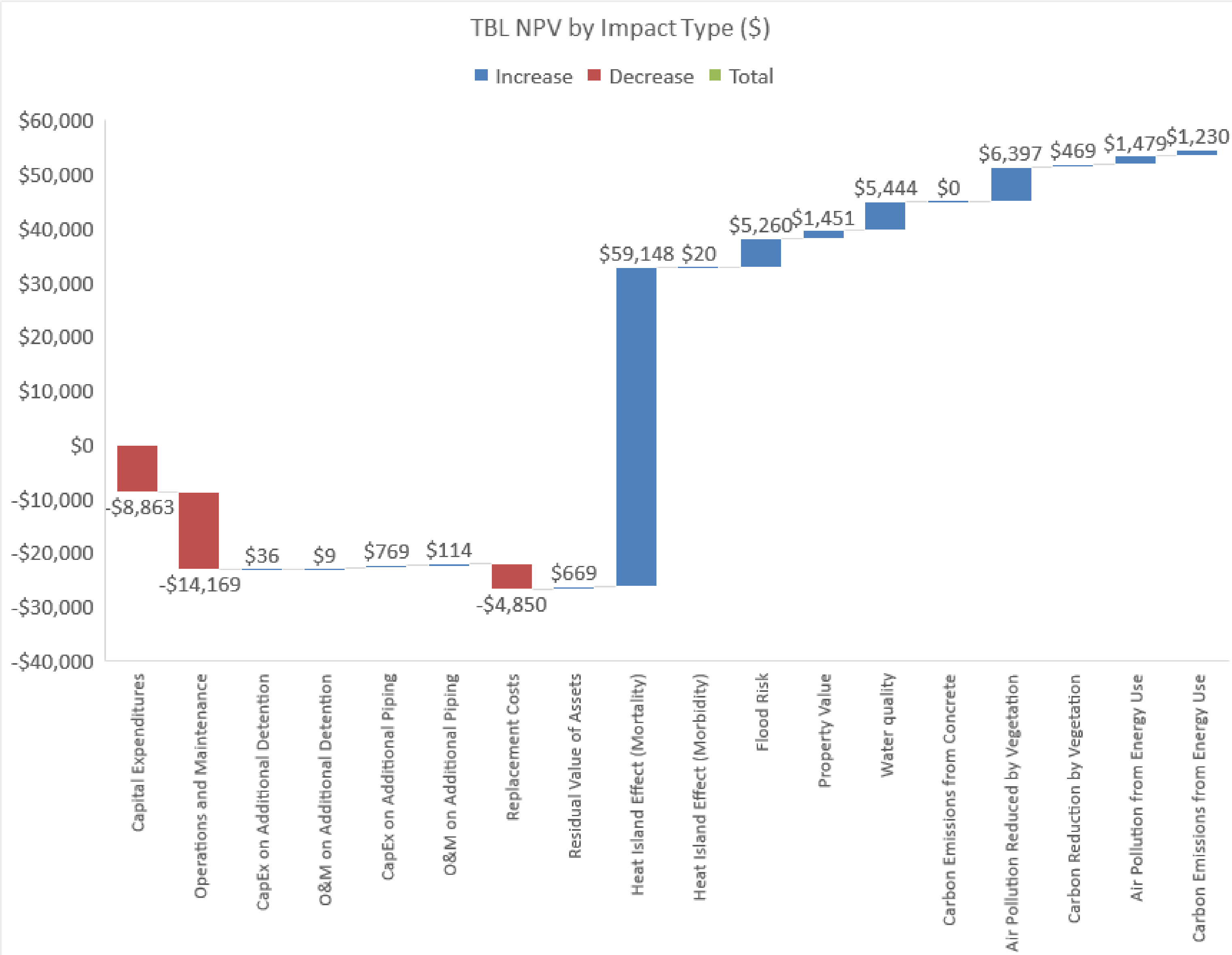

Figure 31: Breakdown of TBL NPV by Impact Type for Primera Iglesia

Table 39: TBL-NPV Results for Each Feature by Impact Type, Primera Iglesia

Impact Type	Cost/Benefit	Mean Value	95% Confidence Interval		
Financial	Capital Expenditures	**-$8,863**	-$8,863	to	-$8,863
Financial	Operations and Maintenance	**-$14,169**	-$16,506	to	-$12,117
Financial	CapEx on Additional Detention	**$36**	$12	to	$60
Financial	O&M on Additional Detention	**$9**	$0	to	$17
Financial	CapEx on Additional Piping	**$769**	$620	to	$988
Financial	O&M on Additional Piping	**$114**	$69	to	$172
Financial	Replacement Costs	**-$4,850**	-$6,114	to	-$3,597
Financial	Residual Value of Assets	**$669**	$501	to	$841
Social	Heat Island Effect (Mortality)	**$59,148**	$41,178	to	$78,135
Social	Heat Island Effect (Morbidity)	**$20**	$20	to	$20
Social	Flood Risk	**$5,260**	$5,260	to	$5,260
Social	Property Value	**$1,451**	$944	to	$1,987
Environmental	Water quality	**$5,444**	$920	to	$11,288
Environmental	Carbon Emissions from Concrete	**$0**	$0	to	$0
Environmental	Air Pollution Reduced by Vegetation	**$6,397**	$4,107	to	$8,651
Environmental	Carbon Reduction by Vegetation	**$469**	$184	to	$851
Environmental	Air Pollution from Energy Use Reduction	**$1,479**	$868	to	$2,220
Environmental	Carbon Emissions from Energy Use Reduction	**$1,230**	$454	to	$2,360
Total	**Triple Bottom Line NPV**	**$54,612**	$23,653	to	$88,273

5.4 Glendale Community Center

Glendale Community Center has a TBL-NPV of $67,000 (95% confidence interval of $30,804 to $107,469) over 50 years and creates around $106,000 in social and environmental benefits. Breaking down the results, we see that O&M costs (-$18,700) and CapEx (-$14,200) are the main drivers of the negative financial results. In terms of social benefits, the tree coverage and LID features generate significant heat island reduction benefits ($78,000) and flood risk reduction ($9,000). There are positive environmental benefits, with around $6,700 through improved water quality, and $9,300 in reduced carbon emissions and air pollution through vegetation and avoided energy use.

Looking at the confidence intervals in Table 40, we can see that there is a fairly tight spread within the financial impacts, suggesting they have less uncertainty surrounding them. The most uncertainty is around heat island effect ($54,463 to $103,344) and water quality ($1,139 to $13,978). When all impacts have been assessed it creates a large spread in overall TBL-NPV of $27,370 to $109,919, but even the low estimate creates a positive TBL-NPV over 50 years.

Financial	Social	Environmental
-$38,455	$89,866	$16,053
Triple Bottom Line NPV		**$67,464**

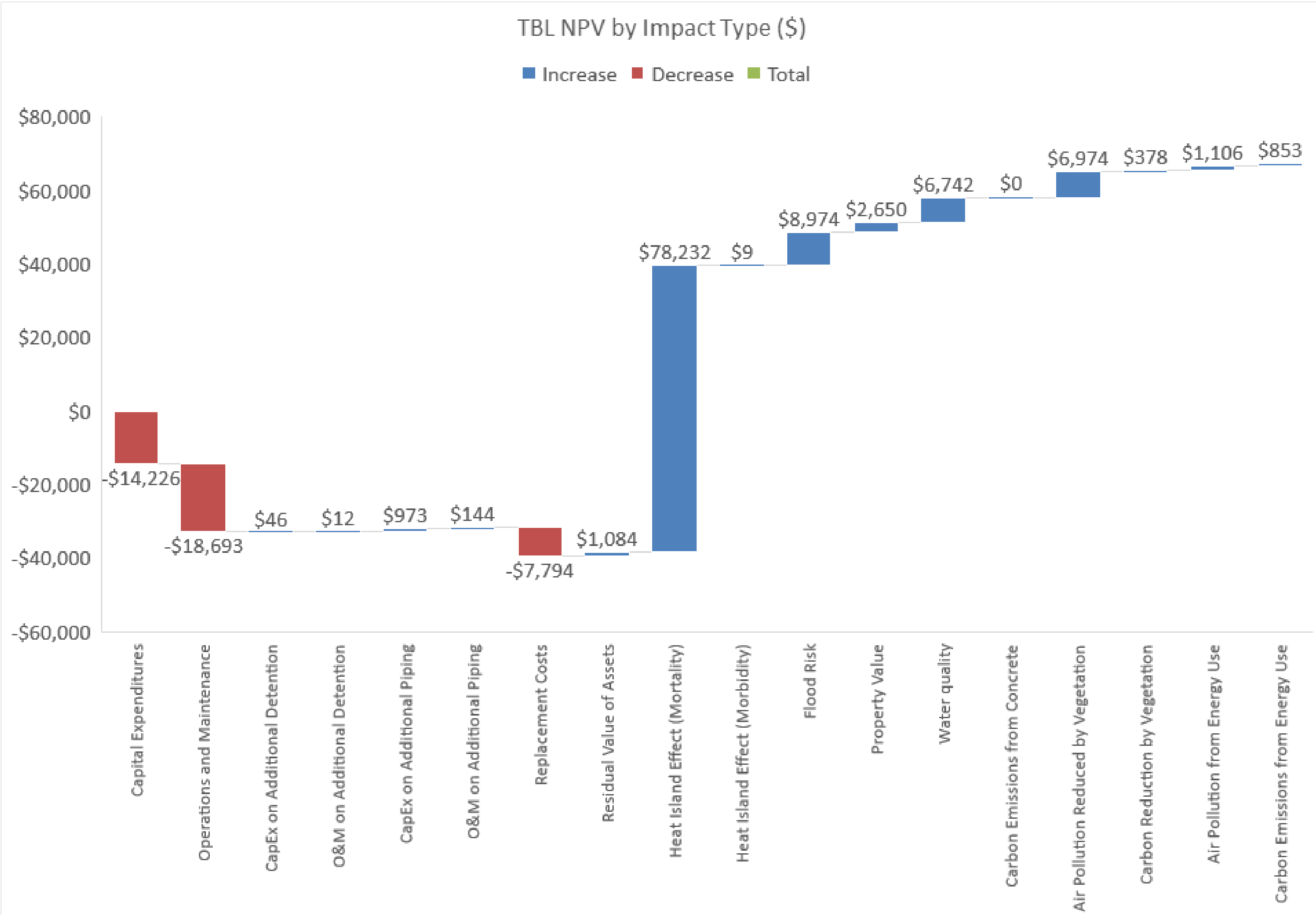

Figure 32: Breakdown of TBL NPV by Impact Type for Glendale

Table 40: TBL-NPV Results for Each Feature by Impact Type, Glendale Community Center

Impact Type	Cost/Benefit	Mean Value	95% Confidence Interval		
Financial	Capital Expenditures	**-$14,226**	-$14,226	to	-$14,226
Financial	Operations and Maintenance	**-$18,693**	-$22,127	to	-$16,243
Financial	CapEx on Additional Detention	**$46**	$15	to	$76
Financial	O&M on Additional Detention	**$12**	$0	to	$22
Financial	CapEx on Additional Piping	**$973**	$785	to	$1,252
Financial	O&M on Additional Piping	**$144**	$88	to	$218
Financial	Replacement Costs	**-$7,794**	-$9,951	to	-$5,635
Financial	Residual Value of Assets	**$1,084**	$788	to	$1,374
Social	Heat Island Effect (Mortality)	**$78,232**	$54,463	to	$103,344
Social	Heat Island Effect (Morbidity)	**$9**	$9	to	$9
Social	Flood Risk	**$8,974**	$8,974	to	$8,974
Social	Property Value	**$2,650**	$1,660	to	$3,645
Environmental	Water quality	**$6,742**	$1,139	to	$13,978
Environmental	Carbon Emissions from Concrete	**$0**	$0	to	$0
Environmental	Air Pollution Reduced by Vegetation	**$6,974**	$4,615	to	$9,306
Environmental	Carbon Reduction by Vegetation	**$378**	$147	to	$703
Environmental	Air Pollution from Energy Use Reduction	**$1,106**	$660	to	$1,534
Environmental	Carbon Emissions from Energy Use Reduction	**$853**	$332	to	$1,587
Total	**Triple Bottom Line NPV**	**$67,464**	$27,370	to	$109,919

5.5 Central Station/Civic Space Park/ Taylor Mall

Central Station/Civic Space Park/Taylor Mall has an overall TBL-NPV of -$170,000 (95% confidence interval of -$1,552,617 to $1,314,054) over 50 years but creates almost $850,000 in social and environmental benefits. The increased cost of implementing the extensive LID features (mainly CapEx from 51,960 square feet of Pervious pavers [$675,000] and 29,826 square feet of Porous concrete [$210,000]) compared to a Concrete alternative results in the negative TBL NPV. Breaking down the results, we see that O&M costs (-$153,000), CapEx (-$576,000), and Replacement Costs (-$334,000) are the force behind the negative TBL NPV results. In terms of social benefits, the tree coverage and LID features generate heat island reduction benefits ($333,000), and flood risk reduction ($65,000). There are positive environmental outcomes, with around $92,000 generated through improved water quality, $282,000 in avoided cost of using concrete, and $61,000 in reduced carbon emissions and air pollution through vegetation and avoided energy use.

Looking at the confidence intervals in Table 41, we can see that there is a significant spread within CapEx (-$915,078 to -$253,456) and Replacement costs (-$617,912 to -$41,247), suggesting they have less certainty surrounding them. There is also large uncertainty around heat island effect ($114,609 to $558,548) and water quality (-$48,719 to $255,721). When all impacts have been assessed it creates a large spread in overall TBL-NPV of -$1,552,617 to $1,314,054, suggesting that there is a good chance that the site could generate either a positive or negative TBL-NPV.

Financial	Social	Environmental
-$1,014,293	$408,123	$435,336
Triple Bottom Line NPV		**-$170,834**

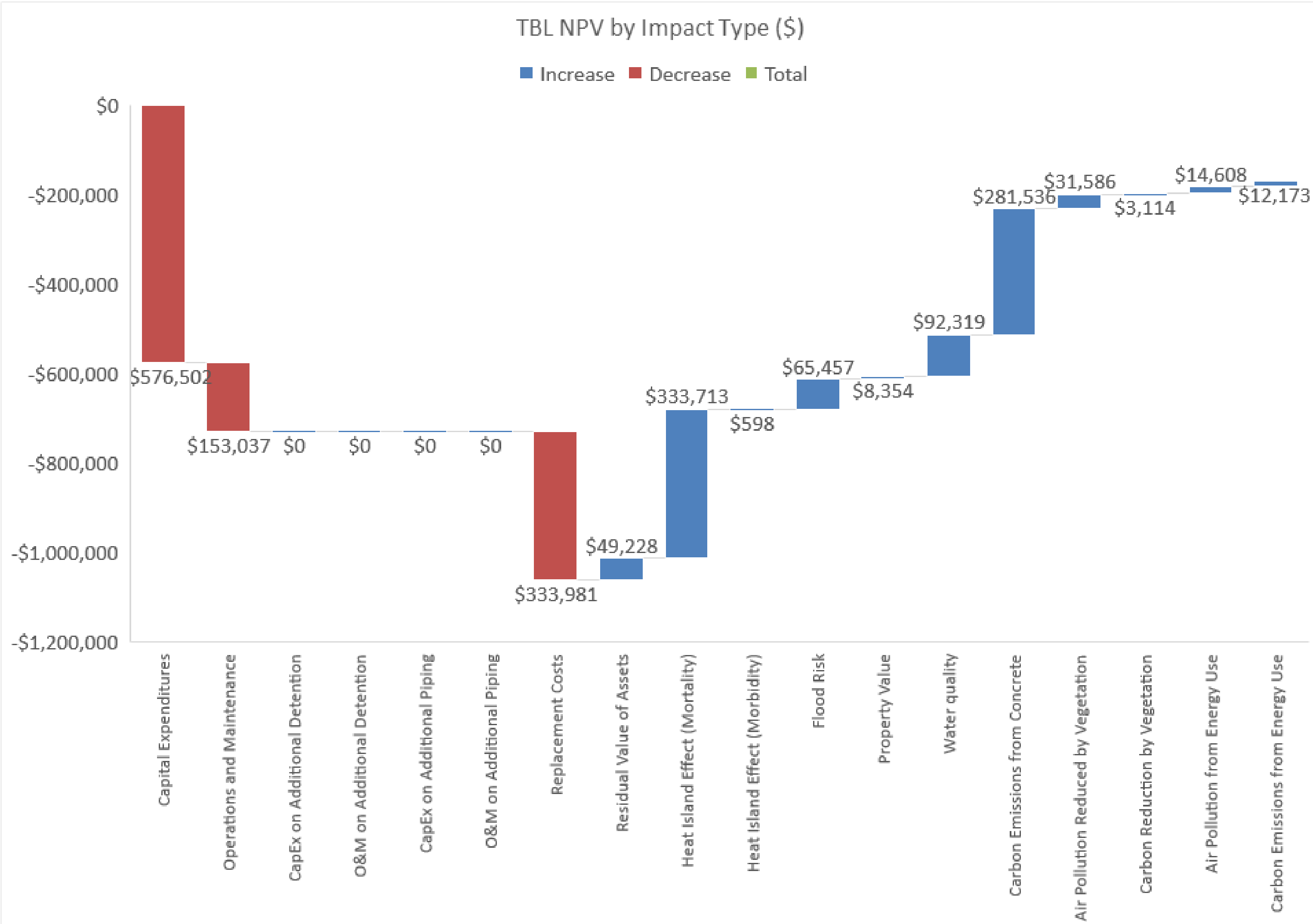

Figure 33: Breakdown of TBL NPV by Impact Type for Central/Civic/Taylor

Table 41: TBL-NPV Results for Each Feature by Impact Type, Central Station/Civic Space Park/Taylor Mall

Impact Type	Cost/Benefit	Mean Value	95% Confidence Interval		
Financial	Capital Expenditures	**-$576,502**	-$915,078	to	-$253,456
Financial	Operations and Maintenance	**-$153,037**	-$202,970	to	-$106,861
Financial	CapEx on Additional Detention	**$0**	$0	to	$0
Financial	O&M on Additional Detention	**$0**	$0	to	$0
Financial	CapEx on Additional Piping	**$0**	$0	to	$0
Financial	O&M on Additional Piping	**$0**	$0	to	$0
Financial	Replacement Costs	**-$333,981**	-$617,912	to	-$41,247
Financial	Residual Value of Assets	**$49,228**	-$73,487	to	$180,993
Social	Heat Island Effect (Mortality)	**$333,713**	$114,609	to	$558,548
Social	Heat Island Effect (Morbidity)	**$598**	-$1,891	to	$3,301
Social	Flood Risk	**$65,457**	$65,457	to	$65,457
Social	Property Value	**$8,354**	$4,164	to	$12,335
Environmental	Water quality	**$92,319**	-$48,719	to	$255,721
Environmental	Carbon Emissions from Concrete	**$281,536**	$117,296	to	$514,838
Environmental	Air Pollution Reduced by Vegetation	**$31,586**	$19,487	to	$43,357
Environmental	Carbon Reduction by Vegetation	**$3,114**	-$1,117	to	$8,109
Environmental	Air Pollution from Energy Use Reduction	**$14,608**	-$2,555	to	$34,417
Environmental	Carbon Emissions from Energy Use Reduction	**$12,173**	-$9,902	to	$38,542
Total	**Triple Bottom Line NPV**	**-$170,834**	-$1,552,617	to	$1,314,054

6 Stakeholder and Policy Consideration

This section was co-authored by Watershed Management Group and The Nature Conservancy and provides an overview of the policy opportunities based on the results of this report and potential steps forward for considering Triple Bottom Line benefits in City of Phoenix projects. City of Phoenix codes and ordinances have been reviewed and are listed below in Section 6.4. The results of the Autocase report justify evaluation of the Triple Bottom Line benefits in project alternatives and the recommendations below provide steps to do that.

6.1 Correlate multiple benefits to City departments & City sustainability goals

It is recommended to clearly communicate the results of the study to relevant departments and stakeholders, as well as to encourage stakeholder involvement and participation. Table 42 lists the co-benefits identified in the study and some of the relevant City and County stakeholders likely to receive those benefits.

Table 42: TBL-NPV: Co-benefits and relevant City and County stakeholders

Co-benefit Identified in the CBA	Benefiting Department(s)
Heat mitigation	Parks and Recreation Department; Office of Homeland Security and Emergency Management; Transit Department; Street Transportation Department; Human Services Department; Office of Sustainability
Flood risk reduction	Planning and Development Department; Office of Homeland Security and Emergency Management; Street Transportation Department (flood-related maintenance), Public Works Department (Floodplain management); Flood Control District of Maricopa County
Carbon emissions	Office of Environmental Programs; Office of Sustainability; Public Works Department
Water quality improvement	Office of Environmental Programs; Water Services Department
Air pollution	Public Works Department; Office of Environmental Programs; Office of Sustainability, Maricopa County Department of Air Quality
Property value uplift	Community and Economic Development, Public Works Department
Health (heat morbidity / mortality)	Maricopa County Department of Public Health

The list above is incomplete, but it provides a starting point for determining which departments may be interested in the results of the study, which co-benefits may carry the most weight, and which department budgets can be tracked to identify any cost offsets or long-term value revealed by the analysis. It is important to communicate the long-term value (in terms of NPV and TBL) of investments in GI/LID to the public, developers, and building owners.

Identifying co-benefits received by specific stakeholders may provide incentive for cost-sharing or co-investment. Departments whose goals are shown to be met in the TBL-CBA might contribute to sharing costs, as might members of the private sector.

The City of Phoenix has identified short and long-term sustainability goals. Table 43 identifies sustainability goals, achievement of which may be aided by the application of GI/LID.

Table 43: TBL: Sustainability Goals related to the GI/LID

Related 2050 Sustainability Goal(s)
Having all residents within a five-minute walk of a park or open space by reducing the urban heat island effect through green infrastructure as well as doubling the current tree and shade canopy to 25% and adding 150 miles of paths, greenways.
Reduce carbon pollution from vehicles, buildings, and waste by 80%-90%.
Provide a clean and reliable 100-year supply of water by reducing dependence on potable water supplies for irrigation and improving water quality downstream of stormwater outfalls
Phoenix will achieve a level of air quality that is healthy for humans and the environment. This includes outperforming all federal standards and achieving a visibility index of good or excellent on 90% of days or more.

6.2 Ensure asset management processes incorporate a broad range of benefits and costs from a TBL perspective in evaluating project alternatives

Many leading utilities and municipalities now explicitly incorporate a range of costs and potential financial, social, and environmental benefits (TBL) when identifying and evaluating project alternatives. Incorporating TBL into asset management has allowed municipalities to deliver projects with amenities and services desired by the public. Two measures the City could implement to incorporate a TBL philosophy are:

- Investigate options for GI/LID early in the planning phase of CIP projects. Cultivate a shift from opportunity-based to need-based projects that will provide the largest TBL benefits. Prioritization of project types and identification of suitable locations for those project types can help with this shift.
- Develop a mechanism for combining revenue sources across departments to encourage implementation of alternatives that provide a greater value when the multiple benefits are calculated. In consultation with the benefiting departments, the City may consider creating an interdepartmental team charged with assembling such a mechanism with accountability to the city manager or council.

6.3 Prioritize by project type and suitability

Based on the results of this study and others in the southwest (i.e., Watershed Management Group studies of Tucson’s Airport Wash Area and Sierra Vista) it is clear that the most sustainable and cost-effective GI/LID retrofit projects have minimal impacts on existing concrete and asphalt. The results show that infrastructure and new projects that utilize natural systems like swales, infiltration basins and trenches have a higher TBL value and avoiding pervious pavers, porous concrete and asphalt is recommended unless they provide an irrigation benefit for shade-producing landscapes or the flood mitigation benefits are required for the project. As such, it is recommended that the City adopt the following prioritization policy when identifying GI/LID project opportunities to maximize the triple bottom line benefits:

- Prioritize natural GI/LID systems (swales, infiltration basins and trenches) in new development
- Prioritize open space and parks for GI/LID retrofits[4] to minimize the need for hardscape removal
- For GI/LID retrofit projects that involve hardscape removal, prioritize projects where there are already plans to fully reconstruct and rebuild the hardscape infrastructure.

6.4 Consider revisions to existing codes and plans

The following is a brief outline of general opportunities to promote GI/LID more broadly throughout a range of City policies, plans, standards and codes. Additional study is needed to refine and prioritize these recommendations:

- *General Plan*
  - In Stormwater section include planning to identify, prioritize, and target areas for new and retrofit GI/LID opportunities
- *Tree and Shade Masterplan*
  - Integrate GI/LID as critical infrastructure to reduce or eliminate outdoor water use in native landscapes while creating a more robust tree canopy
  - Move beyond iTree stormwater benefits of trees by using GI/LID
- *2013 COP Stormwater Policies and Standards*
  - Consider incentives to distribute retention across site
  - The drainage plan design phase for a project should include goals to incorporate GI/LID (e.g., using runoff from impervious surfaces to support vegetation, percent canopy cover for the project area, and utility planning to avoid landscape drainage areas).
  - Emphasize natural channel design practices (not hardening channels but allowing infiltration)

[4] Utilizing stormwater runoff from adjacent landscapes, roads and hardscapes in open spaces and parks (because they don't require hardscape removal) with GI/LID features

6.5 Create a Roadmap

The table below provides a roadmap with general recommendations for mainstreaming GI/LID projects with multiple benefits.

Table 44: Recommended Action and Steps

1. Consult resources, especially EPA's "Case Studies Analyzing the Economic Benefits of Low Impact Development and Green Infrastructure Programs".
2. Involve stakeholders: Clearly communicate the results of the study and address questions of City staff and stakeholders that are answered by the study.
3. Determine whether co-benefits are shared by specific stakeholders and whether those stakeholders may have interest in cost-sharing or co-investment. Consider developing a reserve to provide incentives to implement GI/LID based on site context.
4. Decision-makers at the project level should consider life-cycle costs and net present value from a TBL perspective including community benefits such as flood risk reduction, water quality improvements, air pollution reduction, and heat island mitigation.
5. Work across relevant departments to identify and implement GI/LID in CIP projects, including their maintenance, utilizing the reserve fund (if instituted) to ensure successful implementation. Identify and accommodate new maintenance activities for GI/LID to provide improved NPV, cost-savings, and TBL benefits, including equipment and skill sets.
6. Identify and remove barriers to installation of features that provide a specific threshold for public services or positive NPV (See City of Phoenix Code Review to Promote Green Infrastructure – Case Study)[5]
7. Implement procedure for easy or fast-tracked permitting of private projects with GI/LID components that deliver benefits to the broader community
8. Develop technical guides for residents, businesses, etc. on incorporation of GI/LID into designs, calculation of net present value of benefits. Include information on resources to assist with implementation.
9. Measure and assess performance and costs: Continue to track annual maintenance costs of specific features. Measure performance of installed features for heat reduction, flood mitigation, water quality improvements, and other benefits described in the study. Apply cost-benefit data from the Cost Benefit Analysis to Stormwater Management Models of distributed LID to assess TBL for achieving specific goals related to air quality, flood mitigation, and heat risk reduction.
10. Investigate options for GI/LID options as early as possible in the planning phase of CIP projects. Cultivate a shift from implementing projects which are strictly opportunity-based to integrating need-based projects that will provide the largest benefits. Develop a list of priority areas for LID projects, such as in areas with high heat vulnerability or in areas with localized flooding.

[5] https://wrrc.arizona.edu/sites/wrrc.arizona.edu/files/PHX_Code review to promote green infrastructure case study.pdf

6.6 Resources:

The following resources are available on how other cities have initiated a GI program and managed their assets, which may provide useful information for the City:

1. EPA Case Studies Analyzing the Economic Benefits of Low Impact Development and Green Infrastructure Programs (2013)[6]
2. Philadelphia Combined Sewer Overflow Long Term Control Plan Update, Supplemental Documentation Volume 2, Triple Bottom Line Analysis[7]
3. Urban Land Institute. Harvesting the Value of Water: Stormwater, Green Infrastructure, and Real Estate [8]
4. Seattle Public Utilities Triple Bottom Line Analysis Guidebook[9]
5. Forthcoming study on developing a Green Infrastructure Fund for the City of Tucson

Existing and upcoming documents that provide information on the state of GI policy in Phoenix (in addition to this cost-benefit study) include:

1. City of Phoenix Code Review to Promote Green Infrastructure – Case Study[10] (complete)
2. Green Infrastructure Barriers and Opportunities in Phoenix, Arizona[11] (complete)
3. GI/LID Effectiveness Study (in progress as of June 2018)
4. Identifying Key Areas in the City of Phoenix for Infiltration and Retention Using Low Impact Development – The Nature Conservancy and Bureau of Reclamation (in progress as of June 2018)
5. Guidelines and specifications for GI/LID in Maricopa County – Sustainable Cities Network (in progress as of June 2018)

[6] https://www.epa.gov/sites/production/files/2015-10/documents/lid-gi-programs_report_8-6-13_combined.pdf
[7] http://www.phillywatersheds.org/ltcpu/Vol02_TBL.pdf
[8] https://americas.uli.org/wp-content/uploads/sites/125/ULI-Documents/HarvestingtheValueofWater.pdf
[9] https://tnc.app.box.com/s/hylxegjvfxsl11o8dhqw8gdoktpte01h
[10] https://wrrc.arizona.edu/sites/wrrc.arizona.edu/files/PHX_Code review to promote green infrastructure case study.pdf
[11] https://www.epa.gov/sites/production/files/2015-10/documents/phoenix_gi_evaluation.pdf

7 Conclusions and Caveats

7.1 Conclusion

This short discussion is meant to start the longer conversation of understanding *who* may benefit from GI/LID and *how* these types of multi-account analyses can be used as a tool to galvanize stronger stakeholder buy-in. Breaking down the costs and benefits of GI/LID by each impact type – whether that impact is purely financial or not – provides valuable insights.

Firstly, it enables greater understanding of who may be benefiting from non-traditional forms of capital planning. By thinking of which stakeholders would benefit from each impact, it allows the City to:

1) Assess what existing policies can be leveraged to support GI/LID, as well as how GI/LID may promote the goals of those policies, and
2) Communicate results in a way that gets maximum buy-in from various agencies and external stakeholders. By showing that these projects are aligned with the broader goals of each respective stakeholder, the potential hurdles that often come with more cost-intensive projects can be addressed early.

Multi-account results not only answer the question of "Who benefits?" but equally important, "How much do they benefit?". Providing monetized results across the financial, social, and environmental spectrum enables users to look at projects in a more holistic way, and crucially allowing that holistic analysis to be on an apples-to-apples basis i.e. in dollar terms. Whereas before, we may have only been able to qualitatively state that urban heat island benefits would be generated, we can now put a dollar value to that benefit and compare it against any financial impact. The ability of knowing who benefits and how much they benefit is a powerful tool to build consensus to the delivery of projects and creates an evidence base to promote a shared responsibility to capital planning for these non-traditional projects. The ability to see that the burden of operations and maintenance of a project may fall upon one agency, while creating savings for another agency may provide the impetus for cost sharing.

Finally, these types of analyses give visibility into which features are providing the greatest benefits in terms of the city's priorities. It offers a quick breakdown of where the greatest impacts (whether a cost or benefit) are occurring and enables the City to start thinking of how those impacts can either be mitigated or improved upon. For example, we can see that replacement cost plays a large factor in the financial dis-benefits of the Central/Civic/Taylor project; therefore, by focusing on ways to reduce this replacement cost may mitigate that financial burden. Alternatively, we can see that swales may provide greater urban heat island benefits than Bioretention Basins. Given the heat stress Phoenix faces, users can utilize these types of results to prioritize projects that have the largest impact on that element.

Ultimately, assessing projects across a spectrum of impacts and valuing them in dollar terms allows the City to map benefits and costs to various stakeholders and is an important step toward consensus-building and developing a business case in a way that everyone can understand.

7.2 Caveats

This report is a starting point that can help focus the City's GI/LID efforts to those features more likely to provide long-term value. There are some limitations that should be noted before making policy decisions:

- There is limited local data on CapEx and O&M costs, since this is a fairly recent initiative in Phoenix. We have used a small sample size for Phoenix-specific costs (and partial data for the Central Station/Civic Space Park/Taylor Mall project which led to more estimation on that site), which were supplemented by national averages. Once additional GI/LID projects are completed, a greater inventory of cost information will be available to be refined and make more informed estimates for improved recommendations.
- Replacement costs are based on US-averages; depending on maintenance of the City, as well as local stressors from weather etc., these replacement costs may vary. Nevertheless, we have included low and high estimates to offer a range to reflect this uncertainty.
- The Concrete base case was based on concrete sidewalk or plaza versus roadway and does not include any costs associated with roadbed, grading, and other elements that the street manual requires. As such, the base case likely underestimated costs, including costs of compliance with other required specifications such as grey stormwater infrastructure. The study attempted to capture this through "CapEx and O&M on additional detention and piping" but it is an estimate that could be refined with further analysis and information.
- The above concern also applies to O&M of concrete; stormwater-related O&M costs of a concrete surface need to be included, such as catch basin cleaning (water quality & flooding purposes), stormwater pipe cleaning (flooding). This has been captured to an extent within the water quality estimate (see Methodology Section 8.3.3.4) but could also be refined with further analysis.

8 Methodologies

8.1 TBL-CBA Framework

This project was conducted using a Triple Bottom Line Cost Benefit Analysis (TBL-CBA) framework. TBL-CBA provides an objective, transparent, and defensible business case framework to assess investments in stormwater infrastructure. The proposed analysis broadens traditional financial analysis to incorporate, and value social and environmental factors within an expanded CBA framework. The intent of these analyses is to determine the social and environmental benefits (and dis-benefits), in addition to the lifecycle financial costs and avoided costs that arise from projects.

CBA is a conceptual framework that quantifies in monetary terms as many of the costs and benefits of a project as possible and converting them all into a present day dollar value. In CBA, a "base case" (the existing conditions) is compared to one or more alternatives (which have some significant improvement compared to the base case). The analysis evaluates incremental differences between the base case and the alternative.

To incorporate uncertainty into the analysis, Autocase runs a Monte Carlo based simulation of the possible outcomes and final project value. Low, Expected, and high values are taken from both user inputs and values in literature to reflect the underlying uncertainty in the values used in the CBA. These values are then defined by a distribution and applied to the benefit-cost analysis. This process is then repeated thousands of times to create a probability distribution of the results in the CBA – or 95% confidence intervals, allowing for a more nuanced assessment of project risks.

8.2 Base case

As always with Cost Benefit Analysis (CBA), it is important to factor in the base case – i.e. what would have been built on this site if this feature type were not built? This is vital so that we can estimate the *incremental* benefit from LID, and not just the total benefit.

After discussion with Phoenix staff, the base case feature type used is concrete to reflect the impervious nature of common infrastructure choices. Therefore, when estimating the value of each GI/LID feature type, we compared the benefits versus this 'concrete' feature type for the general feature analysis. Base cases for the case study sites were specific to each site in collaboration with City of Phoenix staff.

8.3 Valuation Methodologies

Autocase automatically values the triple bottom line benefits (or dis-benefits) of numerous impact types. For this assessment, Autocase was used to value:

- Capital expenditure;
- Operations and maintenance costs;
- Replacement costs;
- Residual value;
- Avoided piping and detention costs (both CapEx and O&M)
- Heat Island Effect on both mortality risk and morbidity risk;
- Flood risk;
- Property value uplift;
- Water quality;
- Avoided carbon emissions from concrete;

- Air pollution and carbon emissions reduced by vegetation; and
- Air pollution and carbon emissions reduced by energy savings.

8.3.1 Financial

8.3.1.1 Capital Expenditure

The capital costs for each of the features were based off City of Phoenix and Watershed Management Group project costs that have either been built or are in design, thus representing a local picture of the upfront costs of each of these feature types. For the general feature analysis, because local data was limited (often to only one project's cost), national data was used to supplement local data as needed using EPA SUSTAIN, and National Stormwater Management Calculator and low, expected, and high estimates were put in for each to allow for a risk assessment. Costs were converted into a standard 'per 1,000 square feet' cost. The case studies used project-specific data wherever possible. There were a few gaps in project cost data for the case studies and national data was used to fill in as needed.

8.3.1.2 Operations and Maintenance

Operations and maintenance (O&M) costs are those that accrue throughout the life of the project. In Autocase, they are discounted to produce a present value of the costs. As with capital costs, local O&M costs were provided by the City of Phoenix and Watershed Management Group wherever possible, and for features that did not have costs, Autocase was supplemented with the Green Values Stormwater Toolbox and low, expected, and high estimates were put in for each to allow for a risk assessment. This method was used for both the general features analysis and the case study analysis.

Watershed Management Group O&M costs in this report were determined with five WMG projects: Primera Iglesia in Phoenix and the 4 demonstration sites in Tucson. WMG has two years of maintenance data at Primera Iglesia from 2014-2015 and three years of data at the Tucson demonstration sites from 2014-2017. Site maintenance activities at all sites include sediment removal, weed removal, pruning vegetation and trees, mulching material onsite by hand and trash removal and plant replacement. Maintenance at all sites is a combination of WMG staff and volunteer labor. At Primera Iglesia, volunteer labor was not quantified. At the 4 WMG sites in Tucson, volunteer and staff labor is tracked electronically. Volunteer labor is quantified at 25% efficiency of a regular trained staff hour, so any volunteer labor hours were converted to an equivalent trained employee hour. Labor hours were tracked and then multiplied by the average City of Phoenix landscape maintenance contractor costs of $75/hr. There was 185 hours of maintenance over three years across the four sites (spanning 38,209 sq ft) – equating to 62 hours per year, or 1.6 per 1,000 sq ft. At $75/hr, this comes to $120 per 1,000 sq ft.

A summary of the CapEx and O&M costs are given in the table below. A detailed description of each cost is given in the description for each feature type and site.

Table 45: Summary of Feature Costs

Feature	Unit		Cost ($)		
			Low	Expected	High
Concrete	CapEx	$ per 1,000 sq ft	$4,500	$5,750	$7,000
	O&M	$ per 1,000 sq ft	$0	$0	$0
Swale	CapEx	$ per 1,000 sq ft	$1,124	$5,527	$11,358
	O&M	$ per 1,000 sq ft	$97	$120.95	$151
Porous concrete	CapEx	$ per 1,000 sq ft	$6,370	$7,000	$10,670
	O&M	$ per 1,000 sq ft	$12	$24	$48
Bioretention basin	CapEx	$ per 1,000 sq ft	$2,000	$3,000	$4,000
	O&M	$ per 1,000 sq ft	$97	$121	$151
Infiltration trench	CapEx	$ per 1,000 sq ft	$400	$1,450	$4,200
	O&M	$ per 1,000 sq ft	$97	$121	$151
Pervious pavers	CapEx	$ per 1,000 sq ft	$7,540	$12,970	$17,800
	O&M	$ per 1,000 sq ft	$12	$24	$48
Underground stormwater storage	CapEx	$ per 1,000 cubic foot	$904	$1,205	$1,506
	O&M	$ per 1,000 cubic foot	$1	$1	$6
Trees	CapEx	$ per tree	$160	$591	$739
	O&M	$ per tree	$12	$16	$20
Planter boxes	CapEx	$ per 1,000 sq ft	$550	$8,000	$24,500
	O&M	$ per 1,000 sq ft	$97	$121	$151
Retention basin	CapEx	$ per 1,000 cubic foot	$4,260	$11,550	$22,710
	O&M	$ per 1,000 cubic foot	$15	$30	$60
Porous asphalt	CapEx	$ per 1,000 sq ft	$2,840	$6,330	$9,470
	O&M	$ per 1,000 sq ft	$12	$24	$48
Shrubs	CapEx	$ per 1,000 sq ft	$109	$218	$355
	O&M	$ per 1,000 sq ft	-	-	-

Notes:
- **O&M for shrubs is included within the O&M cost of other features.**

8.3.1.3 Replacement Costs and Residual Value of Assets

Whether the infrastructure is a tree, a Bioretention Basin, a green or traditional roof, or plain concrete, all elements of an infrastructure project need to be replaced at some point. All features types have different lifespans, as well as different costs of replacement at the end of their operating lives. Autocase quantifies these costs as the lifetime "Replacement Costs" of each feature. Replacement costs for features are estimated whenever the expected operating duration of the project exceeds the lifespan of a feature. Replacement costs are then combined with the expected lifespans of each feature type and the operating life of the project to quantify the expected total replacement costs.

Autocase estimates replacement costs as a percentage of initial capital expenditure (using the values listed above). The percent replacement costs are gathered from the EPA's SUSTAIN database. As for useful lives, they are estimated from a number of sources. These sources are used to create a distribution in duration of useful life for each feature type. Sources used include Center for Neighborhood Technology (2006), Toronto and Region Conservation Authority (2013), and City of Toronto (Belanger, 2008).

Table 46: Replacement Costs and Useful Life of Features

Feature	Replacement Cost (% of original)			Useful Life (years)		
	Low	Expected	Max	Low	Expected	Max
Concrete	24	62	100	20	31	50
Swale	41	64	90	20	35	50
Porous concrete	49	74	100	20	28	30
Bioretention Basin	41	64	90	19.99	20	20.01
Infiltration trench	15	17	20	5	10	15
Pervious pavers	66	78	100	20	25	30
Underground stormwater storage	41	64	90	20	34	50
Trees	100	100	100	25	50	75
Planter boxes	41	64	90	5	20	30
Retention basin	41	64	90	25	38	50
Porous asphalt	46	73	100	15	24	30

When a project's operating life comes to an end, many assets may still have an implicit residual value. Depending on the remaining useful life of the asset for each alternative, at the end of the study period, some site elements have a "residual value". The residual value was calculated by determining the assets' useful lives remaining at the end of the period and determining an appropriate value of the asset based on its remaining useful life. Autocase estimates this residual value by assuming straight-line depreciation in the value of all assets/design features. This value is then discounted into present value terms.

8.3.2 Social

8.3.2.1 Heat Island Effect (Mortality)

Heat waves are an increasing danger across North America, occasionally resulting in large numbers of premature deaths. These events may be more frequent and severe in the future due to climate change. GI/LID can reduce the severity of extreme heat events by creating shade and reducing the amount of heat absorbed by pavement and rooftops. Even a small cooling effect can be sufficient to reduce heat stress-related fatalities during extreme heat wave events.

The Urban Heat Island (UHI) effect compromises human health and comfort by causing respiratory difficulties, exhaustion, heat stroke, and heat-related mortality. Various studies have estimated that trees and other vegetation within building sites can reduce temperatures by 5 °F when compared to outside non-green space. At larger scales, variation between non-green city centers and rural areas has been shown to be as high as 9 °F during the day and up to 22 °F during the night.

To quantify heat risk mitigated in Autocase, the first step is determining reduced temperatures in the area because of the project. Figure 34 shows various feature types and the average temperature reduced caused by changing a hypothetical city of all asphalt to that specific feature instead.

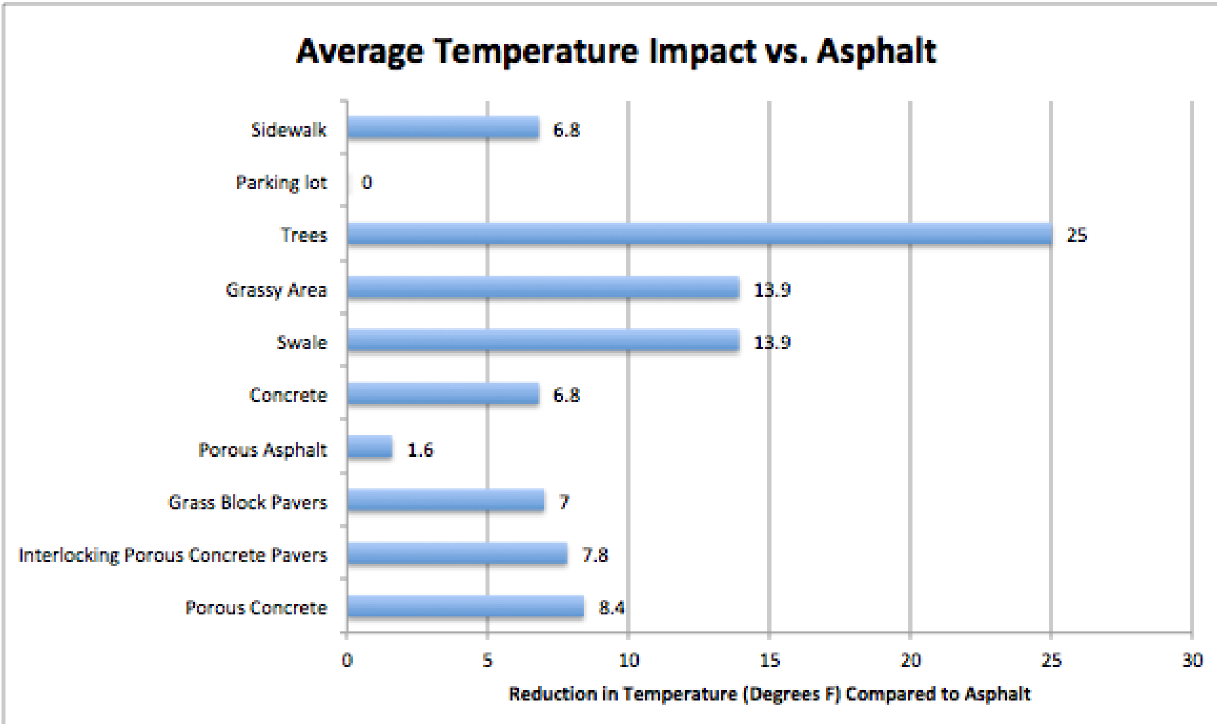

Figure 34: Temperature Changes from Land Cover Change

Using this link, the reduction in temperature is then used to determine avoided death over the life of the project. The reduction in the average annual mortality rate is uses the "higher emissions" scenario mean daily maximum temperature predictions for each month for the 30 years centered around 2050 taken from NOAA for the County[12], the local mortality rate (state-level), and the local (city-level) temperature threshold at which the impacts of heat on mortality can be detected (referred to as the Minimum Mortality Temperature, or MMT). Finally, the Value of Statistical Life, is used to quantify the benefit of reduced heat mortality rates.

8.3.2.2 Value of Statistical Life

The value of a statistical life (VSL) is used when analyzing the risk and reward trade-offs people make. Economists often estimate the VSL by looking at the risks that people take, or say they will take, and how much they are - or must be - paid for taking them. The VSL is widely used in the regulatory impact analysis and cost benefit studies for federal government cost benefit analyses (e.g. safety improvements in rail and roadways). A range of $5m-$13 million with a median around $9 million seems to be accepted. These values are in 2012 US Dollars and are adjusted for inflation depending on the year they are realized.

VSL is not intended to be the value of a specific life. It is the value placed on changes in the likelihood of death, not the price someone would pay to avoid death. Autocase does not place a dollar value on individual lives. Rather, the benefit-cost analysis of infrastructure uses estimates of how much people

[12] Temp in Fahrenheit: Jan = 68.27, Feb = 72.68, Mar = 78.68, Apr = 87.46, May = 96.59, Jun = 105.91, Jul = 108.39, Aug = 106.71, Sep = 102.24, Oct = 92.05, Nov = 78.19, Dec = 69.02

are willing to pay for small reductions in their risks of dying from adverse health conditions that may be caused or improved by the infrastructure.

References Used
(G. B. Anderson & Bell, 2011), (Basu, Feng, & Ostro, 2008), (Curriero et al., 2002), (Mercado, Hudischewskyj, Douglas, & Lundgren), (Medina-Ramon & Schwartz, 2007), (Sailor, 2003), (Zanobetti & Schwartz, 2008), (Voorhees et al., 2011), (NOAA, 2018).

8.3.2.3 Heat Island Effect (Morbidity)

Heat risk does not only affect risk of death, but also heat-related illnesses, which has a social cost in the form of lost productivity in an area. Estimating the value of heat-related illnesses follows a 4-step process:

1. Estimate temperature reduction from change in feature.
2. Estimate avoided heat-related illnesses from the resulting change in temperature.
3. Estimate cost of each heat-related illness
4. Combine, using relevant population for Phoenix.

Firstly, estimating the change in temperature resulting from feature change follows the same process as above for Heat Risk Mortality, details of which can be seen in Figure 34.

Secondly, estimating the change in heat-related illnesses resulting from the temperature change was created using data from Maricopa County. Using daily high temperatures and daily heat related illnesses for Maricopa County, a non-linear relationship between temperature and heat-related illnesses was calculated. From this data, we found that a 1 degree F reduction in temperature (from 102.4F to 101.4F) leads to 96.5 fewer heat-related illnesses per year in Maricopa County (population of roughly 4 million). Using Autocase, we can estimate the temperature reduction from GI/LID, and thus estimate the avoided illnesses per 100,000 people.

Thirdly, we have to calculate the cost of each heat-related illnesses. In order to estimate the social cost of illnesses, we used data from Maricopa County, which gave the percentage breakdown of the number of days spent in hospital due to heat-related illnesses, thus illustrating days out of work. From this, we estimate that the average cost of a heat related illness (in terms of lost wages, and thus lost economic output) is $3,046.

Finally, to calculate the final value, we firstly combine 1) the number of avoided heat-related illnesses per 100,000 people from GI/LID, and 2) the benefit of avoiding each illness, to estimate the value per 100,000 population. Then, applying the population of Phoenix (roughly 1.4 million), we can work out the total annual value for the City as a whole.

8.3.2.4 Avoided Flood Risk

Flood risk is quantified by estimating the percent flood risk mitigated as a result of the project design. As climate change has progressed and rainfall events in some regions have become more extreme, flood risk has become an important consideration in infrastructure development. Autocase quantifies the value of reduced flood risk due to a smaller volume of runoff from the project's property during storm events. Runoff can be reduced by increased green acreage, stormwater storage capacity, stormwater drainage capacity, or reducing the surface area covered by impervious land.

Flood risk is quantified in Autocase by estimating the percent flood risk mitigated in the city because of the project design. The components to this methodology are explained as follows:

1. The first is estimating the total flood risk damage in any given year.
    a. Flood risk is estimated based on historical property value and historical flood damage in each state in the United States.
2. The second component to the flood risk methodology is determining the flood risk mitigated because of the project.
    a. This uses historical rainfall data from over 6,000 weather stations across the United States and Canada, enabling location-specific rainfall data to estimate the rainfall amounts in large storm events each year. Precipitation trends from climate change predictions are also incorporated into the modeling using NOAA's climate explorer (NOAA, 2018).
    b. Estimated flood risk mitigated by the design is equal to the change in retention and infiltration capacity beyond the site's base capacity, divided by the approximate city-wide flood volume in storm events.
    c. The overall flood risk mitigated each year is calculated by multiplying total city property value by the flood risk mitigated.

Although the value at risk increases linearly when compared with storm repeat rate, this actually implies that risk increases exponentially as rainfall depth goes up. This is due to the fact that rainfall levels off as the storm repeat rate goes up. In other words, going from a 10-year storm to a 40-year storm may double rainfall depth from 2.5 inches to 5 inches, but that same doubling from 5 inches to 10 inches may be extremely improbable, even in a 10,000-year storm. In short, for each extra 0.1 inches of rainfall, flood damage is exponentially more costly.

The Autocase flood risk methodology is a dynamic simulation, meaning that for every year in each iteration of the simulation, it produces different risk values. For example, flood risk mitigated due to a decrease of impervious surfaces might be zero for most years. However, in some years there may be rainfall events that are extraordinarily large, at which point there could be massive flooding and the value of reduced flooding due to higher infiltration rates on the site may have value. This is reflected in the Autocase methodology, as there is an element of randomness applied to the rainfall estimates for each year. This means that Autocase's analysis is a better reflection of reality than assuming constant maximum storm strength each year or simply estimating reduced damage value from synthetic design storms, such as 10-, 20-, 50-, and 100-year storms.

References Used
(Hanson & Vogel, 2008); (Nowak & Greenfield, 2012); (Pielke, Downton, & Miller, 2002); (Cronshey, Roberts, & Miller, 1985), (NOAA, 2018).

8.3.2.5 Property Value Uplift/Aesthetic Value

The use of Green Infrastructure (GI) or Low Impact Development (LID) features can lead to increased property prices in a region. The "Property Uplift" benefit in Autocase provides a value estimate of a project's direct impacts on market prices. Most commonly, this value is derived from variations in housing prices, which in some part reflect the value of local environmental attributes. Increases in property values can result from the use of any of the following:

- Trees;
- Shrubs and other plantings;

- Bioretention;
- Rain gardens
- Dry detention pond;
- Infiltration trench;
- Lawn or grassy area;
- Porous pavement;
- Retention pond;
- Green roof;
- Wetlands.

Increased value can be attributed to improved aesthetic value of the local area, temperature-moderating effects of vegetation (thereby decreasing energy costs), reduced risk of flooding, or improved air quality. Many studies have quantified the potential impacts of LID projects on property prices. To estimate this benefit, city-wide average residential prices are used as the baseline property price. Property uplift is then applied to the baseline price to determine the property uplift value. After estimating the total property value increases, the estimate is then multiplied by 50% to account for possible double counting with other benefits included.

References Used
(Braden & Johnston, 2004); (L. M. Anderson & Cordell, 1988); (E. G. McPherson et al., 2006); (Ward, MacMullan, & Reich, 2008); (Wachter & Wong, 2008).

8.3.3 Environmental

8.3.3.1 Carbon Emissions

Newly planted trees, shrubs, grass, and plants can sequester carbon from the atmosphere, reducing the impacts of climate change. Additionally, growing trees, shrubs, grass, and plants can act as carbon 'sinks', absorbing carbon dioxide from the air and incorporating it into their stems or trunks, branches, and roots, as well as into the soil. As with air pollution, plant life often requires maintenance which emits carbon into the atmosphere.

Avoided CO_2 emissions, as well as increased CO_2 sequestration, is a benefit of investing in green infrastructure development. Relative to traditional gray infrastructure (e.g. pipes and water treatment infrastructure), LID may also have less embodied energy. In particular, the use of concrete is a large contributor to net embodied energy in gray infrastructure projects. However, in some cases - notably for green roofs - the net embodied energy may be higher than for traditional infrastructure due to differences in materials used or because more materials are needed.

Autocase quantifies the carbon sequestration rate for all design features in the software, given the available literature on carbon sequestration. It will then value this reduction in carbon emissions by applying the social cost of carbon to the change in total tonnes of avoided CO_2e emissions due to the project. The social cost of carbon used in this assessment follows the Interagency Working Group on Social Cost of Carbon and is valued at $ 41.68 per tonne.

References Used
(Interagency Working Group on Social Cost of Carbon, 2013), (Nordhaus, 2011), (Stern, 2006), (U.S. Energy Information Administration, 2011), (U.S. Environmental Protection Agency, 2013), (U.S. Environmental Protection Agency, 2014).

8.3.3.2 Air Pollution

For the purposes of this study, Criteria Air Contaminants (CACs) are considered air pollutants emitted by combustion engines, which affect the health of people immediately in their vicinity. Air pollution, or CACs, is removed from the environment by trees and shrubs. As these grow throughout the life of the project they capture air pollutants at an increasing rate.

The air pollutants reduced on site include mono-nitrogen oxides (NOx), sulphur dioxide (SO_2), volatile organic compounds (VOCs), and particulate matter smaller than 2.5 micrometers ($PM_{2.5}$). The air pollution is valued by multiplying by the social cost of each pollutant ranges from $6,730/tonne for NOx to $14,190/tonne for $PM_{2.5}$.

Table 47: Social Cost of Pollutants

Variable	Unit	Value
CO	$ per Metric Ton	$30.48
SO_2	$ per Metric Ton	$48,168
NO_2	$ per Metric Ton	$8,150
$PM_{2.5}$	$ per Metric Ton	$372,815
O_3	$ per Metric Ton	$1,442

References Used
(Cai, Wang, Elgowainy, & Han, 2012), (European Comission, 2005), (Mike Holland, 2002), (Friedrich, Rabl, & Spadaro, 2001), (Matthews & Lave, 2000), (G. E. McPherson, Nowak, & Rowntree, 1994), (Muller & Mendelsohn, 2010), (U.S. Environmental Protection Agency, 2014).

8.3.3.3 Avoided Air Pollution and Carbon Emissions due to Reduced Energy Use

Trees modify climate and conserve building energy use in three principal ways:

1. Shading—reduces the amount of radiant energy absorbed and stored by built surfaces.
2. Transpiration—converts liquid water to water vapor and thus cools by using solar energy that would otherwise result in heating of the air.
3. Wind speed reduction—reduces the infiltration of outside air into interior spaces and conductive heat loss, especially where thermal conductivity is relatively high.

Trees provide greater energy savings in the Desert Southwest region than in milder climate regions because of the long, hot summers. Trees near buildings can reduce the demand for heating and air conditioning, thereby reducing emissions associated with electric power production. Autocase then uses the same principal as above to calculate the avoided emissions and the resulting social benefit from that.

The work by (G. McPherson et al., 2004) estimate that public trees save 77-181 kWh per year in electricity and around 229 kBTU in natural gas.
Applying this to our case study sites:

- For the Central Station LID design, there are 44 trees (44*180 kWh = 7,920 kWh saved per year and 44*229 =10,076 kBTU saved per year). For the traditional design, we assume 34 trees (34*180 kWh = 6,120 kWh and 34*229kBTU = 7,786 kBTU saved per year)

- Primera Iglesia LID design has 15 trees, resulting in an estimated annual saving of 2,700 kWh and 3,435 kBTU. The base case would have had no trees, and thus no resulting energy or natural gas savings.
- The Glendale site has 8 trees, resulting in an estimated annual saving of 1,440 kWh and 1,832 kBTU. The base case would have had no trees, and thus no resulting energy or natural gas savings.

References Used

McPherson E.G., J.R. Simpson, , J.R.; Peper, P.J.; Maco, S.E.; Xiao, Q.; Mulrean, E. 2004. Desert Southwest Community Tree Guide: Benefits, Costs and Strategic Planting. Arizona Community Tree Council, Inc. Phoenix, AZ. 76 p.

8.3.3.4 Water Quality

Increased acres of vegetation, including forests or wetlands, can positively influence the water quality in a local area by reducing surface runoff of pollutants into local waters.

Phoenix has a separate storm sewer system, so runoff does not get treated by a wastewater treatment plant (WWTP). Most stormwater in Phoenix goes directly to a surface water (dry wash, river, or retention basin) untreated. Per Section 6.8 of the City of Phoenix Stormwater Policies and Standards Manual (2013), developments are required to “retain water from the 100-year, 2-hour duration storm falling within property boundaries” or provide “first flush” stormwater treatment. In the latter case, first flush runoff may pass through either a hydrodynamic separator or a filter catch basin insert before going in to the storm system.

Hydrodynamic separators use the energy of flowing water to help separate out sediments, as opposed to more traditional settling chambers, and is designed to capture settleable solids, floatables, oil and grease.

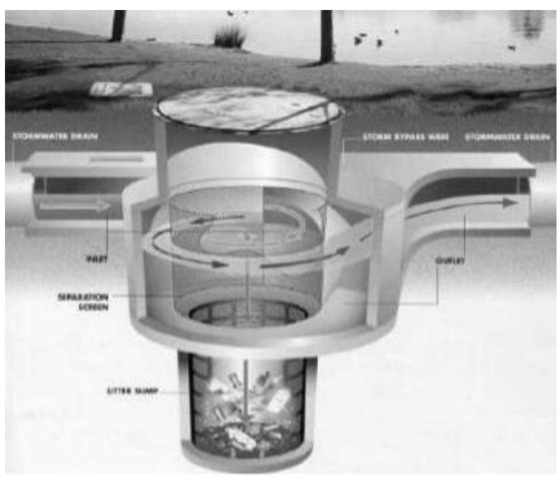

Figure 35: Hydrodynamic Separator

Source: PIMA County, 2015. “Low Impact Development and Green Infrastructure Guidance Manual”.

Filter catch basin inserts consist of a deep basket with a fabric liner that filters the storm water. In addition, oil absorbent pads are placed in the basket for removal of petroleum hydrocarbons. The inserts are held in place by the catch basin grate. Typically, the filter is specifically designed to fit the Maricopa Association of Governments (MAG) catch basin and can be inserted directly into existing catch basins.

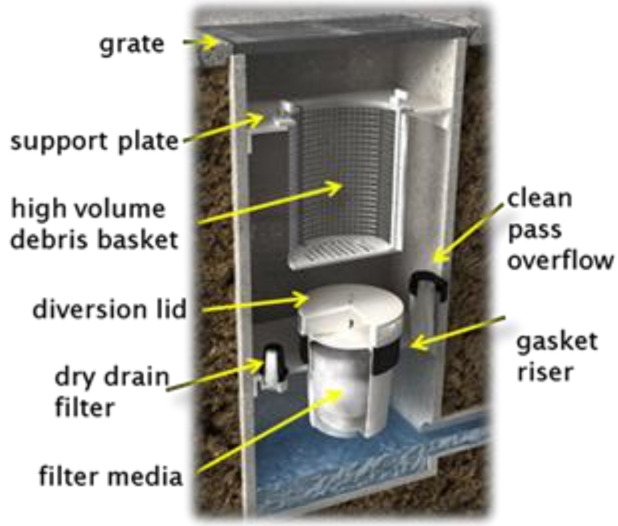

Figure 36: Catch Basin Filter Insert

Source: PIMA County, 2015. "Low Impact Development and Green Infrastructure Guidance Manual".

We model the value of improved water quality by estimating the reduced runoff that would be passing through these gray systems due to having LID present on the site (and the water passing through the LID before reaching these systems) and equate that to the cost avoided in CapEx and O&M for the gray system. Historical rainfall are supplemented by NOAA's RCP8.5 climate predictions (NOAA, 2018).

The model calculations are given in the tables that follow. Cost data was provided by the City of Phoenix for each system, which is given in the table below.

Table 48: Cost Information for Filter Catch Basin Inserts and Hydrodynamic Separator

	Low	Medium	High
System	No system	Filter catch basin insert	4-foot Hydrodynamic separators
System size acreage	N/A	1.16	1.16
CapEx ($)	$0	-$900	-$16,000
O&M ($ per year)	$0	-$500	-$2000
Useful life (year)	N/A	30	30

Notes:
The lifecycle cost information was provided by the City from a recent project at the City 22nd Ave Service Center, 2441 S 22nd Ave.

From these inputs, we calculated the present value of the lifecycle costs over a 50-year period to estimate the total cost of ownership of each system, results of which are in *Table 49*.

Table 49: Lifecycle Cost (Total Cost of Ownership) of Each System

Lifecycle costs (present value over 50 years)			
	Low	**Medium**	**High**
System	Filter catch basin insert	Filter catch basin insert	4-foot Hydrodynamic separators
CapEx	$0	-$900	-$16,000
O&M	$0	-$12,500	-$24,200
Residual value	$0	$66	$170
Replacement cost	$0	-$360	-$1,960
Total cost	$0	-$13,694	-$41,990

Notes:
The costs are just for the systems themselves and do not include installation, concrete removal or replacement that may be needed on top of that.

After calculating the present value of lifecycle costs, we then determine the size of system needed in the base case. For example, if one system is designed for 1.16 acres, then on a per square foot basis, 0.3 systems are needed for the 15,000 sq ft (0.344 acres) drainage area we are using for the general feature analysis. We then calculate the reduced runoff passing through the system due to each LID being implemented for the 15,000 sq ft drainage area and estimate the resulting number of systems that would be needed. For example, if the LID halves the runoff, we would need half the system. We then find the corresponding system cost for the design case. Finding the difference in cost between the amount of system needed in the base case and the cost for the amount of system needed under the LID scenario is the value of water quality. The results are summarized in Table 50.

The low cost corresponds to no system being put in place, the medium cost is for the filter catch basin insert covering 1.16 acres, and the high estimate is for the 4-foot hydrodynamic separator covering 1.16 acres.

Table 50: Water Quality Valuation Method for Phoenix

		Conc	Swale	Por conc	Bio basin	Inf tren	IPCP	Por asph	PI	Glen	C/C/T trad	C/C/T LID
Number of systems needed for 15,000 sq ft base case.		0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.40	0.49	8.88	8.88
Cost of system for base case	Low	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Med	$4,065	$4,065	$4,065	$4,065	$4,065	$4,065	$4,065	$5,419	$6,775	$121,593	$121,593
	High	$12,465	$12,465	$12,465	$12,465	$12,465	$12,465	$12,465	$16,615	$20,774	$372,842	$372,842
Runoff in LID scenario as a % of runoff in base case		100%	42%	58%	43%	64%	58%	58%	11%	12%	75%	8%
Number of systems needed for 15,000 sq ft with 1,000 sq ft LID.		0.30	0.12	0.17	0.13	0.19	0.17	0.17	0.04	0.06	6.70	0.75
Cost of system with LID	Low	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Med	$4,065	$1,697	$2,377	$1,744	$2,599	$2,377	$2,377	$612	$823	$91,776	$10,269
	High	$12,465	$5,203	$7,289	$5,348	$7,968	$7,290	$7,290	$1,876	$2,523	$281,414	$31,486
Savings from LID	Low	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Med	$0	$2,368	$1,688	$2,321	$1,466	$1,688	$1,688	$4,807	$5,952	$29,817	$111,325
	High	$0	$7,262	$5,175	$7,117	$4,497	$5,175	$5,175	$14,739	$18,252	$91,428	$341,356

Notes:
Conc = Concrete, Swale = Swale, Por conc = Porous Concrete, Bio basin = Bioretention basin, Inf tren = Infiltration trench, ICPC = Pervious pavers, Por asph = Porous Asphalt, PI = Primera Iglesia, Glen = Glendale Community Center, C/C/T trad = Central/Civic/Taylor traditional design, C/C/T LID = Central/Civic/Taylor LID design.

9 List of References

Anderson, G. B., & Bell, M. L. (2011). Heat waves in the United States: mortality risk during heat waves and effect modification by heat wave characteristics in 43 US communities. *Environmental health perspectives, 119*(2), 210.

Anderson, L. M., & Cordell, H. K. (1988). Influence of trees on residential property values in Athens, Georgia (USA): A survey based on actual sales prices. *Landscape and Urban Planning, 15*(1), 153.

Basu, R., Feng, W. Y., & Ostro, B. D. (2008). Characterizing temperature and mortality in nine California counties. *Epidemiology (Cambridge, Mass.), 19*(1), 138. doi:10.1097/EDE.0b013e31815c1da7 [doi]

Braden, J. B., & Johnston, D. M. (2004). Downstream economic benefits from storm-water management. *Journal of Water Resources Planning and Management, 130*(6), 498.

Cai, H., Wang, M., Elgowainy, A., & Han, J. (2012). *Updated greenhouse gas and criteria air pollutant emission factors and their probability distribution functions for electricity generating units*. Retrieved from

Cronshey, R. G., Roberts, R. T., & Miller, N. (1985). *Urban hydrology for small watersheds (TR-55 Rev.).* Paper presented at the Hydraulics and Hydrology in the Small Computer Age.

Curriero, F. C., Heiner, K. S., Samet, J. M., Zeger, S. L., Strug, L., & Patz, J. A. (2002). Temperature and mortality in 11 cities of the eastern United States. *American Journal of Epidemiology, 155*(1), 80.

European Comission. (2005). Damages per tonne emission of EU25 Member State (exclud ing Cyprus) and surrounding seas March 2005. (March).

Friedrich, R., Rabl, A., & Spadaro, J. V. (2001). Quantifying the costs of air pollution: the ExternE project of the EC. *Pollution Atmospherique*, 77-104.

Hanson, L. S., & Vogel, R. (2008). *The probability distribution of daily rainfall in the United States.* Paper presented at the World Environmental and Water Resources Congress.

Interagency Working Group on Social Cost of Carbon. (2013). Technical update on the social cost of carbon for regulatory impact analysis-under executive order 12866. *Interagency Working Group on Social Cost of Carbon, United States Government*.

Matthews, H. S., & Lave, L. B. (2000). Applications of environmental valuation for determining externality costs. *Environmental Science & Technology, 34*(8), 1390-1395.

McPherson, E. G., Simpson, J. R., Peper, P. J., Gardner, S. L., Vargas, K. E., Maco, S. E., & Xiao, Q. (2006). Piedmont community tree guide: benefits, costs, and strategic planting.

McPherson, G., Simpson, J. R., Peper, P. J., Maco, S. E., Xiao, Q., & Mulrean, E. (2004). *Desert Southwest Community Tree Guide: Benefits, Costs and Strategic Planting*. Retrieved from https://www.fs.usda.gov/treesearch/pubs/47703

McPherson, G. E., Nowak, D. J., & Rowntree, R. A. (1994). Chicago's urban forest ecosystem: results of the Chicago Urban Forest Climate Project.

Medina-Ramon, M., & Schwartz, J. (2007). Temperature, temperature extremes, and mortality: a study of acclimatisation and effect modification in 50 US cities. *Occupational and environmental medicine, 64*(12), 827. doi:10.1136/oem.2007.033175 [doi]

Mercado, M. E., Hudischewskyj, A. B., Douglas, S. G., & Lundgren, J. R. Meteorological and Air Quality Modeling to Further Examine the Effects of Urban Heat Island Mitigation Measures on Several Cities in the Northeastern Us.

Mike Holland, P. W. (2002). *Benefits Table Database: Estimates of the Marginal External costs of air pollution in Europe*. Retrieved from

Muller, N. Z., & Mendelsohn, R. O. (2010). Weighing the value of a ton of pollution. *Regulation, 33*(2), 20.

NOAA. (2018). Climate Explorer. Retrieved from http://toolkit.climate.gov/climate-explorer2/

Nordhaus, W. D. (2011). *Estimates of the social cost of carbon: background and results from the RICE-2011 model*. Retrieved from

Nowak, D. J., & Greenfield, E. J. (2012). Tree and impervious cover change in US cities. *Urban Forestry & Urban Greening, 11*(1), 21.

Pielke, R. A., Downton, M. W., & Miller, J. Z. B. (2002). *Flood damage in the United States, 1926-2000: a reanalysis of National Weather Service estimates*: University Corporation for Atmospheric Research Boulder CO.

Sailor, D. J. (2003). Streamlined mesoscale modeling of air temperature impacts of heat island mitigation strategies. *Final report.Portland, OR: Portland State University.Available: web.cecs.pdx.edu/~ sailor/FinalStreamline ReportEPA2003.pdf [accessed 13 July 2006]*.

Stern, N. (2006). What is the economics of climate change? *WORLD ECONOMICS-HENLEY ON THAMES-, 7*(2), 1.

U.S. Energy Information Administration. (2011). Voluntary Reporting of Greenhouse Gases Program. *US Department of Energy, Energy Information Administration*.

U.S. Environmental Protection Agency. (2013). *eGRID 2012 Files*. Retrieved from: http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html

U.S. Environmental Protection Agency. (2014). Emission Factors for Greenhouse Gas Inventories. (April), 1-5.

Voorhees, A. S., Fann, N., Fulcher, C., Dolwick, P., Hubbell, B., Bierwagen, B., & Morefield, P. (2011). Climate change-related temperature impacts on warm season heat mortality: a proof-of-concept methodology using BenMAP. *Environmental science & technology, 45*(4), 1450.

Wachter, S. M., & Wong, G. (2008). What Is a Tree Worth? Green-City Strategies, Signaling and Housing Prices. *Real Estate Economics, 36*(2), 213.

Ward, B., MacMullan, E., & Reich, S. (2008). The effect of low-impact-development on property values. *Proceedings of the Water Environment Federation, 2008*(6), 318.

Zanobetti, A., & Schwartz, J. (2008). Temperature and mortality in nine US cities. *Epidemiology (Cambridge, Mass.), 19*(4), 563. doi:10.1097/EDE.0b013e31816d652d [doi]

10 Appendices

10.1 Appendix A: Feature Type Results Breakdown with Design Storm Sensitivity

The following table shows the breakdown by impact type when the 24-hour design storm is varied. As outlined earlier in the report, the results in the body of the report are for a 1-inch 24-hour storm, but the table below also shows results for 0.5-inch and 2-inch storms.

In Autocase, the design storm only affects the additional piping and detention impacts (CapEx and O&M). If a feature type can absorb all three storms, then there should be no change.

As we can see in Table 51, all the feature types have the same savings versus Concrete for CapEx and O&M on additional piping and detention.

Table 51: Storm Sensitivity Results for GI/LID Feature Types

Feature/Site	Design Storm	CapEx on Additional Detention	O&M on Additional Detention	CapEx on Additional Piping	O&M on Additional Piping
Swale	0.5-inch	$24	$6	$505	$76
	1-inch	$24	$6	$505	$76
	2-inch	$24	$6	$505	$76
Bioretention basin	0.5-inch	$24	$6	$505	$76
	1-inch	$24	$6	$505	$76
	2-inch	$24	$6	$505	$76
Infiltration trench	0.5-inch	$24	$6	$505	$76
	1-inch	$24	$6	$505	$76
	2-inch	$24	$6	$505	$76
Pervious pavers	0.5-inch	$24	$6	$505	$76
	1-inch	$24	$6	$505	$76
	2-inch	$24	$6	$505	$76
Porous concrete	0.5-inch	$24	$6	$505	$76
	1-inch	$24	$6	$505	$76
	2-inch	$24	$6	$505	$76
Porous asphalt	0.5-inch	$24	$6	$505	$76
	1-inch	$24	$6	$505	$76
	2-inch	$24	$6	$505	$76

10.2 Appendix B: Case Sites Results Breakdown with Design Storm Sensitivity

The following table shows the breakdown by impact type when the 24-hour design storm is varied. As outlined earlier in the report, the results in the body of the report are for a 1-inch 24-hour storm, but the table below also shows results for 0.5-inch and 2-inch storms.

In Autocase, the design storm only affects the additional piping and detention impacts (CapEx and O&M). If a feature type can absorb all three storms, then there should be no change.

As we can see in Table 52, Primera Iglesia does not have any savings under the 0.5-inch design storm versus its base case. However, under the 1-inch design storm there are savings of roughly $900. This increases to around $3,200 under the 2-inch design storm, indicating the avoided need to use additional piping and detention.

For Glendale Community Center, there are zero savings versus the base case under the 0.5-inch design storm. Under the 1-inch and 2-inch design storms, there is roughly $1,200 and $4,000, respectively in savings from avoiding having to use additional piping and detention.

Lastly, for Central/Civic/Taylor, we can see that there are zero savings under each design storm, indicating that there is already enough capacity under the base case design i.e. the LID design does not avoid any additional piping and detention.

Table 52: Storm Sensitivity Results for Case Study Sites

Feature/Site	Design Storm	CapEx on Additional Detention	O&M on Additional Detention	CapEx on Additional Piping	O&M on Additional Piping
Primera Iglesia	0.5-inch	$0	$0	$1	$0
	1-inch	$36	$9	$769	$114
	2-inch	$237	$60	$2,516	$372
Glendale Community Center	0.5-inch	$0	$0	$1	$0
	1-inch	$46	$12	$973	$144
	2-inch	$301	$76	$3,187	$471
Central/Civic/ Taylor	0.5-inch	$0	$0	$0	$0
	1-inch	$0	$0	$0	$0
	2-inch	$0	$0	$0	$0