December 20, 2011

Determining the Potential of Green Infrastructure to Reduce Overflows in Milwaukee

MMSD Contract No: M03002P01
MMSD File Code: M009PE000.P7400

Prepared for:

mmsd
Preserving The Environment • Improving Water Quality
Milwaukee Metropolitan Sewerage District
260 W Seeboth Street
Milwaukee, WI 53204

Prepared by:

2020 Facilities Plan Team:
Brown AND Caldwell
HNTB
TETRA TECH

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Executive Summary

The Milwaukee Metropolitan Sewerage District (MMSD) is a regional government agency that provides water reclamation and flood management services for about 1.1 million customers in 28 communities. As part of its Water Pollution Abatement Program (WPAP), MMSD invested $3 billion in grey infrastructure over three decades through the mid-1990s. From the late 1990s to 2010, the MMSD spent an additional $900 million in grey infrastructure on the *Overflow Reduction Plan* that was developed as part of the *2010 Facilities Plan*.

Before 1994, when the Deep Tunnel System and other WPAP improvements went into operation, the MMSD sewer system had between 50 and 60 overflows per year, with an annual average volume of 8 billion to 9 billion gallons of overflow. Today, that number is down to only about two overflows per year, with an annual average of one billion gallons of overflow.

MMSD has proposed an ultimate goal of eliminating all sewer overflows by the year 2035. Green infrastructure will be a critical component of meeting this goal, especially given the District's heavy investment to date in grey infrastructure. To further evaluate the potential of green infrastructure to help eliminate overflows, MMSD conducted this study to assess the ability of a variety of practices to detain, evapotranspire, and infiltrate stormwater within the combined sewer service area (CSSA). Many of the lessons learned are also applicable to the sanitary service area (SSSA).

Potential benefits are measured based on environmental outcomes (e.g., overflow, peak stream flow, and pollutant loading reductions) as well as economic (e.g., new jobs created, property values) and social (e.g., quality of life, aesthetics) outcomes. This holistic approach to measuring benefits is referred to as a Triple Bottom Line (TBL) analysis. A *symphony modeling* approach made it possible to use a series of watershed, sewer system, and green infrastructure models to evaluate how the stormwater and wastewater systems impact one another.

To evaluate the potential impact of green infrastructure within the entire CSSA, a screening-level analysis was conducted using the MACRO model. The MACRO model is a simple, volumetric model used to simulate the overall response of the MMSD conveyance and treatment system to a wide range of hydrologic conditions. Green infrastructure in the CSSA is represented in the MACRO model by converting impervious area to pervious area. In the baseline case there are approximately 4,000 acres of pervious area out of a total of 15,000 acres. Three cases of increasing application of green infrastructure are modeled; these cases increase the pervious area by 400, 1,000, and 2,000 acres from the baseline value. The particular technologies used to implement green infrastructure are not defined in the MACRO model, only the value of pervious area is defined.

The conversion of impervious areas to pervious areas results in less combined sewer overflow (CSO) volume and reduced frequency of CSO events in the long-term MACRO model simulations. The baseline average CSO volume of 771 million gallons (MG) per year is reduced 7 percent in the 400-acre conversion case, 11 percent in the 1,000-acre case, and 19 percent in the 2,000-acre case. The frequency of CSO events is estimated to be reduced from the baseline value of 3.1 CSO events per year to 2.9 CSO events per year in the 400-acre case; CSO events are reduced to 2.7 in the 1,000-acre case and 2.2 in the 2,000-acre case. Although the model results are different than the actual observed overflows (2 overflows per year observed compared to 3.1 per year modeled) because different time periods were used for the comparisons, the model shows the relative impacts on overflows that would be anticipated if green infrastructure was implemented in a manner that corresponds to the model.

The simulated volume and number of CSO events in any particular year vary, depending on the size and number of large hydrologic events in each year. The results of the long-term simulations indicate the overall impact of green infrastructure averaged over many decades, but do not indicate the level of CSO reduction that should be expected in any given every year. Lesser CSO events demonstrate the most noticeable percent CSO reduction. The cumulative benefit of many small CSO events is the source of the overall reduction in CSO volume and frequency. For larger wet weather events the absolute value of the CSO reduction is of the same order of magnitude, but the percent reduction is small relative to the large volume of CSO.

The analysis conducted with the MACRO model confirms the potential of green infrastructure to have a significant impact on average annual CSO volumes and events in Milwaukee. However, the model is limited in its ability to fully simulate the potential hydrologic and water quality benefits of green infrastructure. For example, representing green infrastructure simply as the conversion of impervious areas to pervious areas does not account for the potential to route runoff from impervious areas to new green infrastructure. In addition, it does not fully simulate the processes associated with different green infrastructure practices (i.e., increased evapotranspiration provided by bioretention, infiltration rates above natural background due to placement of underdrains).

The System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN) model was therefore applied to a pilot area within the CSSA to allow for a more detailed analysis and to determine the most cost-effective set of green infrastructure practices for runoff volume reduction.

SUSTAIN is a model developed by the U.S. Environmental Protection Agency (USEPA) to evaluate alternative plans for water quality management and flow abatement techniques in urban areas. The development of SUSTAIN represents an intensive effort to create a tool for evaluating, selecting, and placing green infrastructure practices in an urban watershed on the basis of user-defined cost and effectiveness criteria. SUSTAIN provides a public domain tool capable of evaluating the optimal location, type, and cost of stormwater green infrastructure practices needed to meet water quality goals.

Three sewersheds south of Capitol Drive and west of the Milwaukee River in the City of Milwaukee were chosen for the pilot SUSTAIN evaluation. These sewersheds were chosen because they are considered representative of the entire CSSA in terms of soil conditions and topography, for example, and because they include a mix of residential, commercial, industrial, and transportation areas to which a variety of green infrastructure practices are applicable.

Each of a variety of green infrastructure practices (rain gardens, block bioretention, regional bioretention, bio-swales, rain barrels, green roofs, porous pavement, and green alleys) was evaluated for applicability within the pilot area based on a review of aerial imagery. Applicability was based on available land or roof area and proximity to sources of runoff and pollutants.

Applicability and green infrastructure practice specifications in the SUSTAIN model assume a mix of fill and native clay-rich soils, with a background soil infiltration rate of 0.15 inch per hour. Based on the aerial photography analysis, the potential locations of each type of green infrastructure practice were digitized in a geographic information system (GIS) to determine the maximum opportunity boundaries to be evaluated by SUSTAIN. Representative drainage areas were set for each practice, although detailed routing analyses were not conducted to confirm that those areas could always be effectively drained to the practices.

Figure ES-1 shows the average annual stormwater runoff volume reduction cost-effectiveness curve for the study area as a result of running the SUSTAIN model for a representative 10-year period. In this figure, the small points represent all solutions that were evaluated during optimization, while the larger points along the left-and-upper-most perimeter represent the least cost options at each volume reduction interval. The maximum achievable volume control through the use of all potential green infrastructure practices within the study area is around 85 percent; however, there is clearly a point above which the marginal costs of additional controls increases dramatically. To further investigate this, four solutions at different intervals along the curve (the larger, highlighted points on the curve) were selected for detailed performance evaluation.

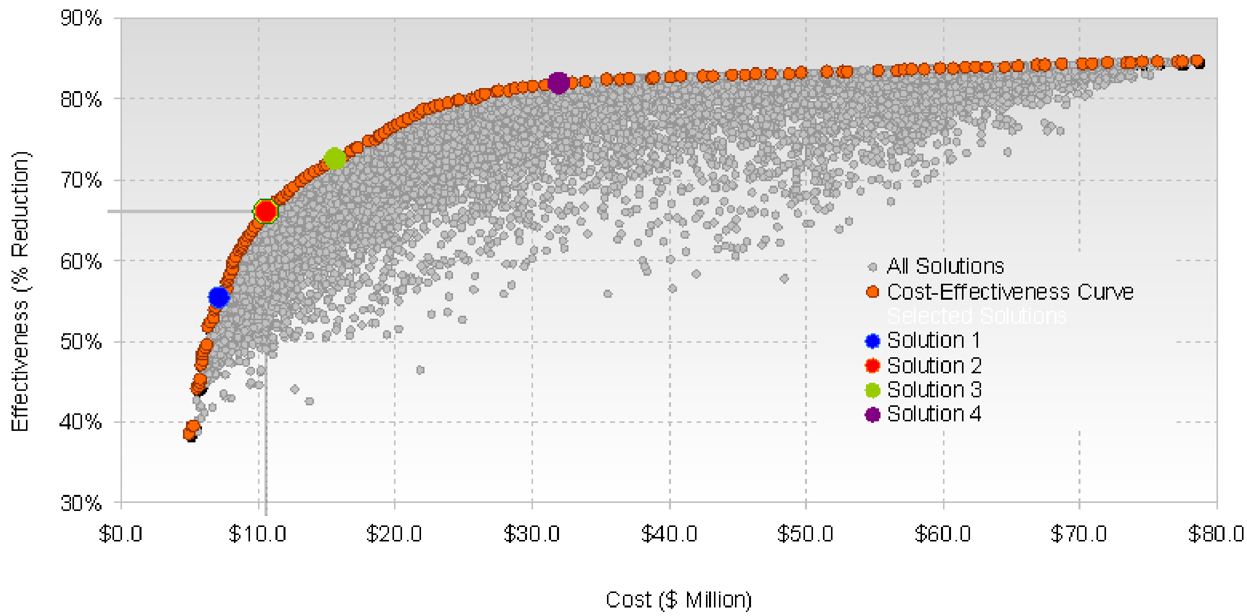

Figure ES-1. Maximum Runoff Volume Control Cost-effectiveness Curve.

The utilization percentage of each practice for the four solutions is plotted in Figure ES-2. Percent utilization for each solution is defined as the ratio of how much of the available opportunity was used divided by the total available opportunity. Figure ES-2 illustrates how utilization changes for each practice as cost and percent volume control increases while moving up the curve. The percent volume control for each solution is shown in parenthesis.

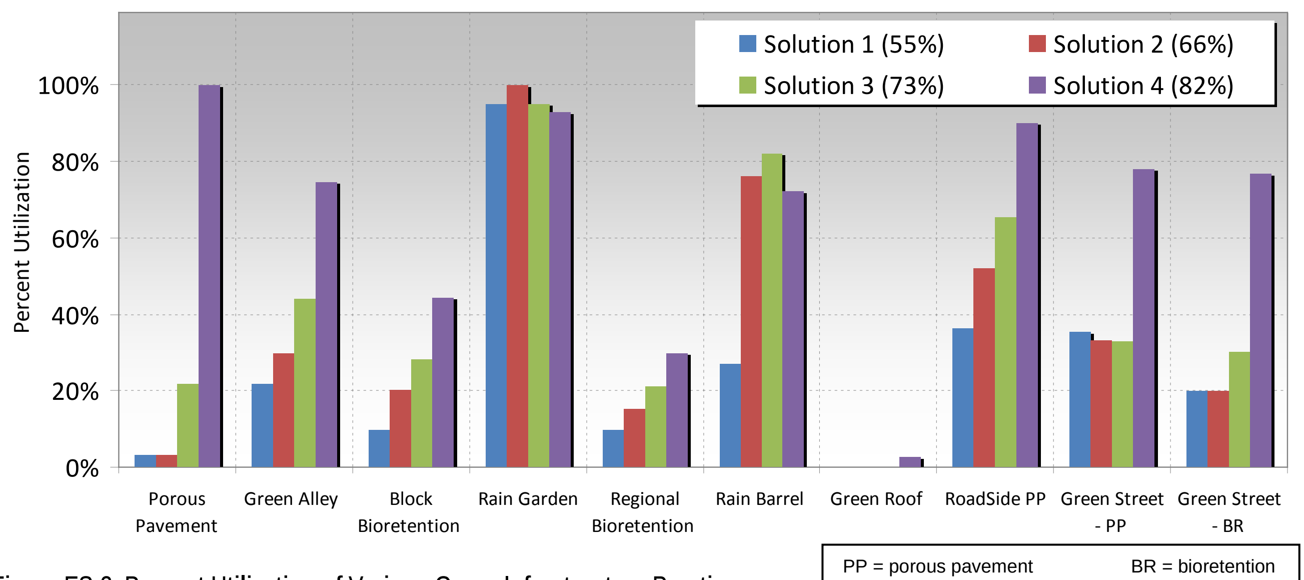

Figure ES-2. Percent Utilization of Various Green Infrastructure Practices.

Several of the important observations resulting from the SUSTAIN analysis include:

- Rain gardens were the most widely utilized practice for each of the four selected solutions. This indicates that rain gardens are the most cost-effective practice in these cases. The utilization rate of rain gardens reached 100 percent for solution 2; however, utilization dropped slightly in solutions 3 and 4, because additional treatment capacity was provided by block and regional bioretention.
- The utilization of rain barrels shows an upward trend at higher treatment levels, however there was a slight decrease in solution 4 because of the decreased use of rain gardens. Rain barrels and rain gardens were modeled as being used in series; therefore, rain barrels act as supplemental storage to extend the infiltration potential of rain gardens.
- The adoption of porous pavement increased dramatically from 3 percent to about 22 percent at the 73 percent flow reduction mark, and then increased to 100 percent to achieve flow volume reduction beyond 82 percent.
- The utilization of block bioretention, green alleys, regional bioretention, road side porous pavement, and green streets is always less than 100 percent. This indicates that the maximum potential extent of these practices exceeds the corresponding drainage area. Increasing the use of these practices above this maximum value therefore only increases cost without realizing any additional benefit.
- The SUSTAIN results indicate a general trend of diminishing performance with increasing storm size. However, the decrease in performance is less significant at higher treatment levels (e.g., solutions 3 and 4) because of the added capacity provided by more practices.
- The runoff volume, peak flow, and pollutant removal percentages for total suspended solids (TSS), total nitrogen (TN), and total phosphorus (TP) are listed for the four selected solutions in Figure ES-3 and Table ES-1. It shows a trend of increasing average percent reduction moving up the cost effectiveness curve; it also shows a decline in the rate at which most pollutant removal increases with advanced treatment. However, the rate at which the peak flow reduction increases continues to increase with increasing treatment level.

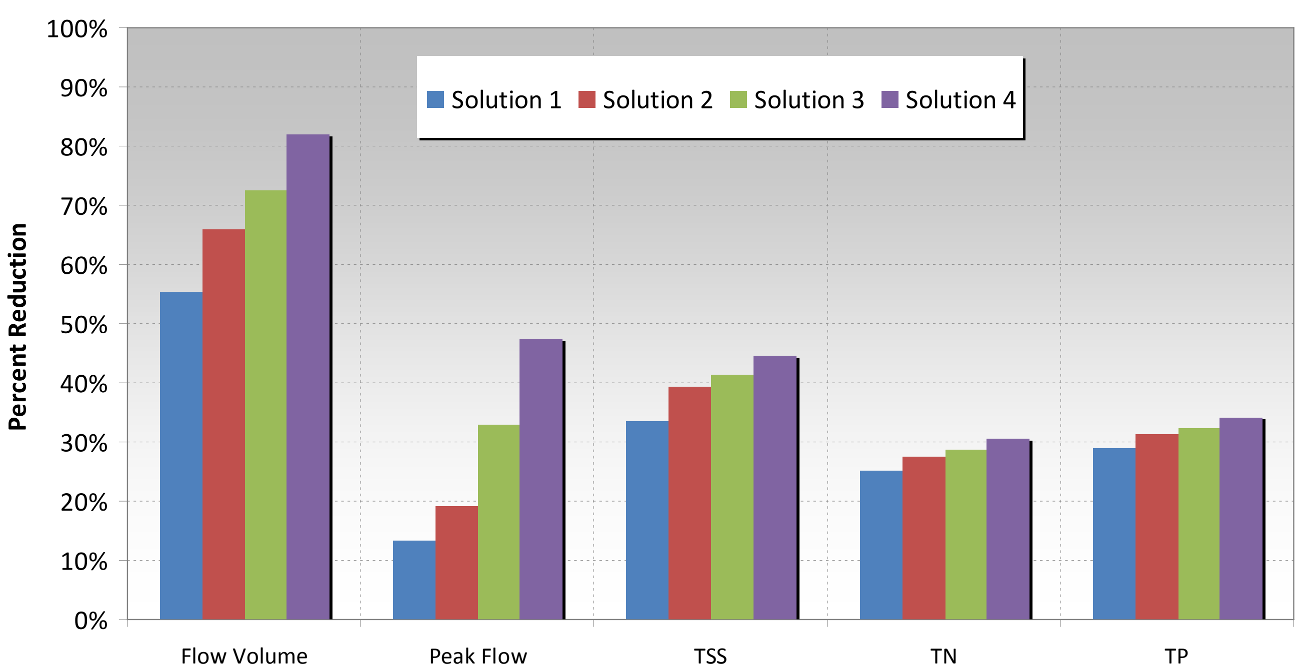

Figure ES-3. Flow Volume, Peak Flow, and Pollutant Loading Reductions of the Four Selected Solutions.

Table ES-1. Pollutant Reductions of the Four Selected Solutions within the Pilot Area.

Solution ID	Volume control	Peak flow	TSS	TN	TP	Cost ($ millions)
Solution 1	55.4%	13.4%	33.5%	25.1%	29.1%	7.2
Solution 2*	66.0%	19.2%	39.5%	27.6%	31.3%	10.6
Solution 3	72.6%	32.9%	41.4%	28.9%	32.3%	15.7
Solution 4	81.9%	47.5%	44.6%	30.7%	34.1%	32.0

*Solution used to support TBL Analysis

Although the SUSTAIN pilot application was performed on an area within the CSSA, green infrastructure can have a similar if not greater impact in the SSSA. Each of the practices simulated in SUSTAIN can also be used within the SSSA and some may be even more effective. For example, the pilot SUSTAIN application assumed residential rain gardens could only be 50 square feet in size due to the small yards. To the extent that there are larger yards in the SSSA, rain gardens could also be made larger. In addition, the water quality benefits of green infrastructure will be much more significant in the SSSA because each pound of pollutant treated is a pound that would otherwise be loaded into the nearest waterway. In contrast, most pollutant runoff in the CSSA is already treated, even without green infrastructure, because it is routed to the water reclamation facilities except when overflows occur. The results of the SUSTAIN application described in Section 3 are therefore directly relevant to what would be expected to occur within the SSSA. The potential negative impacts of using green infrastructure in the SSSA, such as increased infiltration or inflow, are far outweighed by the benefits and can be mitigated by addressing the underlying cause of the problem (i.e., fix leaking pipes), or locating infiltrating practices away from the sanitary sewer or surrounding trench. In some cases, green infrastructure can be used to reduce infiltration volumes using detention.

This study confirms that a strategic use of green infrastructure along with traditional grey infrastructure can be an effective method of reducing overflows in Milwaukee. To evaluate potential impacts throughout the entire CSSA, solution 2 from the SUSTAIN modeling of the pilot area was used to inform a fourth run of the MACRO model. Green infrastructure in solution 2 represents nearly 225 acres of impervious surface drainage area out of a total impervious area of 297 acres, or 76 percent. This ratio was applied to the total impervious area of the CSSA (10,725 acres) to identify that 8,125 impervious acres should be converted to pervious acres in the MACRO model run. The results suggest that with this high level of conversion, the simulated average annual CSO volume (155 MG) is approximately one fifth of the baseline value (771 MG) and the simulated average CSO frequency is less than one event per year. Note that even with 100 percent of the impervious area converted to pervious land use, the simulation shows CSOs would still occur. It should be noted that this simulates an extremely high level of adoption of green infrastructure and is intended primarily to provide an upper bound for what may be possible. Furthermore, there is some uncertainty as to the actual amount of imperviousness in the CSSA, with the value used in MACRO potentially being too high. Additional, more detailed modeling within the CSSA will be needed to obtain a better understanding of the potential for green infrastructure throughout the entire CSSA.

MMSD understands that moving from a grey to a green and grey infrastructure system means change, and that change will require community support and strong partnerships. To build this support, it is important to report on the full spectrum of green infrastructure benefits: the social, economic, and environmental, and to show that the preferred solution hits the TBL. Indeed, social marketing studies show that to motivate change, one must first illustrate how a desired action improves people's daily lives (e.g., more beautiful neighborhoods, higher property values, improved safety, increased jobs). The next step in motivating change is to emphasize environmental stewardship benefits. Therefore, a TBL analysis was conducted to evaluate a broader range of environmental benefits alongside important economic and social benefits, and to determine the degree to which each of the green infrastructure practices contributes to the bottom line.

The analysis provides a compelling illustration of the magnitude and breadth of green infrastructure benefits in the pilot area. Key findings from the analysis include the following:

- Through improved aesthetics, a property value increase totaling $2.7 million.
- Through job creation, an annual reduction of $220,000 in social costs, with a present worth of $2.7 million over 20 years.
- Through reduced tunnel pumping costs, a present worth savings of $46,000 over 20 years.
- Through green alleys and bioretention areas, an 11-acre increase in recreation area.
- Through control and treatment of runoff, 435 acre-feet of reduced runoff per year, 68 US tons of reduced sediment loading per year, and 406 acre-feet of increased groundwater recharge per year.
- Through carbon sequestration, reduction of 156 tons of carbon dioxide over 20 years equivalent to annual carbon emissions from 2,652 automobiles and 1,318 single family homes.
- Through shade, reduction of 64,000 kWh in energy use and $3,900 to $5,700 in energy savings over 20 years.
- Additional benefits through improved quality of life, improved air quality, enhanced drainage, and protection of public health (reduced risk of getting sick when contacting river water).

Considering that green infrastructure may represent part of the overall CSO volume reduction strategy, these practices would provide long-term economic, social, and environmental benefits beyond what grey infrastructure alone can provide. Numerous studies support these findings, and most notable among the findings is the reduction in social costs due to poverty and the increases in property value. Some of the benefit estimates appear relatively small because the pilot area is small; however, as green infrastructure is considered for a larger portion of the CSSA, the benefits will increase accordingly.

In an effort to estimate the TBL benefits for the entire CSSA, the pilot area benefits determined for solution 2 were linearly extrapolated based on area. A factor of 25 was used to extrapolate the results, derived from the ratio of the entire CSSA area to the pilot area. The extrapolation assumes that land uses, soils, weather, average property values and the applicability of green infrastructure in the rest of the CSSA are identical to those in the pilot area. The extrapolation also assumes that hydrology and green infrastructure will behave in the same way within the entire CSSA. Using this linear extrapolation, the estimated green infrastructure TBL benefits for the entire CSSA include:

- Through job creation, an annual reduction of $5.5 million in social costs, with a present worth of $68 million over 20 years.
- Through porous pavement and green alleys, 66 to 77 percent reduction in per unit storage costs.
- Through reduced pumping costs, a present worth savings of $1.2 million over 20 years.
- Through improved aesthetics, a property value increase totaling $68 million.
- Through green alleys and bioretention areas, a 275-acre increase in recreation area.
- Through control and treatment of runoff, 10,875 acre-feet of reduced runoff per year, 1,700 US tons of reduced sediment loading per year, and 10,150 acre-feet of increased groundwater recharge per year.
- Through carbon sequestration, reduction of 3,900 tons of carbon dioxide over 20 years equivalent to annual carbon emissions from 66,300 automobiles and 32,950 single family homes.
- Through shade, reduction of 1,800,000 kWh in energy use and $98,000 to $143,000 in energy savings over 20 years.

A more detailed review of land use, aerial photography, and other data is needed to ensure that applicability is representative. However, this level of analysis is outside the scope of this project.

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1 Introduction

The Milwaukee Metropolitan Sewerage District (MMSD) is a regional government agency that provides water reclamation and flood management services for about 1.1 million customers in 28 communities in Greater Milwaukee. MMSD serves 411 square miles that span parts of six watersheds. As part of its Water Pollution Abatement Program (WPAP), MMSD invested $3 billion in grey infrastructure over three decades through the mid-1990s. Grey infrastructure, as it relates to stormwater and wastewater, includes conveyance systems, deep tunnels, and treatment facilities. Before 1994, when the Deep Tunnel System and other WPAP improvements went into operation, the MMSD sewer system had between 50 and 60 overflows per year, with an annual average volume of 8 billion to 9 billion gallons of overflow. Today, that number is down to only about two overflows per year, with an annual average of one billion gallons of overflow. MMSD substantially completed a $1 billion Overflow Reduction Plan that included additional Deep Tunnel system capacity, sewer construction and rehabilitation projects, treatment plant improvements, scientific research, and planning at the end of 2010 and is continuing to work on reducing sewer overflows.

MMSD has proposed an ultimate goal of eliminating all sewer overflows by the year 2035. Green infrastructure will be a critical component of meeting this goal, especially given the District's heavy investment to date in grey infrastructure. Green infrastructure is defined by the U.S. Environmental Protection Agency as "an approach to wet weather management that is cost-effective, sustainable, and environmentally friendly. Green infrastructure management approaches and technologies infiltrate, evapotranspire, capture and reuse stormwater to maintain or restore natural hydrology".

To further evaluate the potential of green infrastructure to help eliminate overflows, MMSD conducted this study to assess the ability of a variety of practices to detain, evapotranspire, and infiltrate stormwater within the combined sewer service area (CSSA). Many of the lessons learned are also applicable to the separate sanitary service area (SSSA). Potential benefits are measured based on environmental outcomes (e.g., overflow, peak stream flow, and pollutant loading reductions) as well as economic (e.g., new jobs created, property values) and social (e.g., quality of life, aesthetics) outcomes. This holistic approach to measuring benefits is referred to as a TBL analysis.

The project team describes the overall approach to evaluating the complex stormwater and wastewater systems as *symphony modeling*. This term is used to describe how each model plays a role in analyzing certain components of the system and works together with the other models to provide information that can be used to make informed decisions. In the same way, grey infrastructure and green infrastructure must also be designed and implemented to work together like a symphony to provide the most cost effective solution to improve water quality and reduce overflow volumes.

This report summarizes the results of the following four efforts:

- Screening- level assessment of the impact of converting impervious areas to pervious areas within the entire CSSA using the MACRO model (Section 2);
- Detailed optimization analysis of green infrastructure practices in a pilot area of the CSSA using the System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN) model and estimated impacts to CSOs (Section 3);
- Evaluation of the potential benefits and challenges to widespread application of green infrastructure within the SSSA (Section 4); and
- Analysis of the combined environmental, economic, and social outcomes (TBL) associated with green infrastructure (Section 5).

2 Screening-Level Assessment within the Entire Combined Sewer Service Area

2.1 Introduction to the Modeling Approach

The MACRO model is a simple, volumetric model used to simulate the overall response of the MMSD conveyance and treatment system to a wide range of hydrologic conditions. The MACRO model is a screening level model that was developed to simulate flows in the MMSD sewer system. The MACRO model was used in the 2020 Facilities Plan analysis along with the MOUSE hydraulic model. The MOUSE model was used for detailed hydraulic simulations of the MMSD conveyance system and the MACRO model was used for simplified screening level investigations to quickly evaluate the system-wide impact of various planning alternatives. Both the MACRO model and the MOUSE model were driven by the continuous simulation results of the Hydrologic Simulation Program in Fortran (HSPF) model. Furthermore, the modeling parameters used to generate the flows in MACRO are based on the calibration parameters used to generate the flows for the MOUSE model. Thus the calibration of the MACRO model is closely related to the calibration of the MOUSE model and the modeling results between the two models are consistent (within the intrinsic limitations of the simple MACRO modeling environment). Neither the MOUSE model nor the MACRO model include other water resource related issues such as stream flow in rivers or groundwater flow in the region; the models are intended to be used to evaluate the MMSD conveyance system only.

In the MACRO model the MMSD service area is divided into four, large, lumped modeling areas (two for the separate sanitary service area (SSSA) and two for the combined sewer area). Subsystems one through four are represented as one composite SSSA and subsystems five through eight as a separate composite SSSA in MACRO. In the Combined Sewer Service Area (CSSA) the model has one composite area for the high level system and another for the low level system.

The model can be used for long-term simulations that span the full period of record and for simulating individual wet weather events. However, MACRO does not compute results at specific manholes or specific overflow locations. Instead, the results are cumulative volumes treated, stored, and bypassed for each of the four simplified modeling areas.

The baseline simulation for this analysis used a configuration of the MACRO model that represents the facilities recommended by the 2020 Facilities Plan for a 5-year level of protection against sanitary sewer overflows (SSOs). This model formulation uses the projected 2020 population and land use values that were used in the 2020 Facilities Plan report for system-wide modeling (the revised future 2020 values). The model configuration includes the North 27th Street Inline Storage System (ISS) extension, additional pumping capacity in the ISS pump station, and the recommended additional physical/chemical secondary treatment at the South Shore Water Reclamation Facility (WRF). The operational parameters and the simulation conditions used for the baseline case are summarized in Table 2-1. There are approximately 15,000 acres in the CSSA.

The baseline simulation was used as a reference to evaluate relative changes in overflow volume and frequency for three cases in which a portion of the estimated impervious area is converted into pervious area. For the purpose of this screening-level model run, it is assumed that the converted areas will have a hydrologic response similar to the existing pervious areas. The MACRO model calibration parameters are used along with the HSPF model to generate the flows in the sewer system. The hydrologic processes in HSPF are active groundwater flow, interflow, and surface runoff. The MACRO model parameters give weight to the various hydrologic processes in HSPF that contribute to sewer flow. (Surface runoff from pervious surface areas is not modeled in MACRO as a specific soil type and is not defined by a characteristic infiltration rate into the soil. Instead, the hydrologic processes in the MACRO model are aimed at an accurate generation of flow into the sewer system based on the output from the HSPF simulation results).

Table 2-1. Operational Parameters and Long-term Simulation Conditions.

Parameter	Value
ISS volume	432 MG (includes the N 27th Street ISS extension)
VRSSI	197 MG
Jones Island Water Reclamation Facility peak capacity	360 MGD (includes up to 60 MGD of blending)
South Shore Water Reclamation Facility peak capacity	450 MGD (includes 150 MGD of physical/chemical secondary treatment)
ISS pump out limit to Jones Island	180 MGD
ISS pump out limit to South Shore	40 MGD
Northwest side relief sewer harbor siphon improvements	on-line on-line
Meteorological input source	General Mitchell International Airport (January 1940 - June 2004)
Population and land use conditions	2020 baseline
CSSA area	14,838 acres

ISS = Inline Storage System VRSSI = Volume Reserved for Separate Sewer Inflow
MG = Million Gallons MGD = Million Gallons per Day

2.2 Long-Term Simulations: Average Combined Sewer Overflow Volume and Combined Sewer Overflow Frequency

Long-term simulations were based on the 64.5-year rainfall record at the General Mitchell International Airport (GMIA) from January 1940 to June 2004 (this is the same period that was used in the development of the 2020 Facilities Plan). In the MACRO model, wastewater flow is generated in the combined and separate sewer areas. The wastewater is composed of the base sanitary flows and the hydrologic response to wet weather events that enter the conveyance system as infiltration and inflow (including surface runoff in the combined sewer area). The model accounts for the rate of wastewater treated at the Jones Island and South Shore Water Reclamation Facilities (WRFs). Excess wastewater that cannot be treated is stored in the ISS for later treatment after the event. When the ISS fills, the remaining excess wastewater that cannot be treated is allowed to overflow as combined sewer overflow (CSO) and SSO discharges. The simulation results contain the cumulative overflow volumes and the number of overflow events from which the average annual overflow volumes and the average frequency of overflow events can be calculated.

Green infrastructure in the CSSA is represented in the MACRO model by converting impervious area to pervious area. This is based on the assumption that pervious land in the MACRO model functions similarly to green infrastructure in that it allows for increased infiltration, evapotranspiration, and storage compared to impervious land. A more sophisticated representation of green infrastructure is not feasible within the MACRO model and is one of the reasons SUSTAIN was used to evaluate a pilot project area (see Section 3).

In the baseline case there are approximately 4,000 acres of pervious area. Three cases of increasing application of green infrastructure are modeled; these cases increase the pervious area by 400, 1,000, and 2,000 acres from the baseline value. The particular technologies used to implement green infrastructure are not defined in the MACRO model, only the value of pervious area is defined. For the purposes of this MACRO analysis, green infrastructure was only applied to the CSSA. Section 4 discusses the potential impacts of green infrastructure on the SSSA.

Table 2-2 summarizes the change in pervious area for the three cases. In the first case, approximately 400 acres are converted to pervious land use compared to the baseline configuration. In the second case, approximately 1,000 acres are converted. In the third case, 2,000 acres are converted. Table 2-2 also summarizes the long-term simulation results for CSO average annual overflow volumes and average CSO overflow frequencies. The baseline average CSO volume of 771 MG per year is reduced 7 percent in the 400 acre conversion case. Greater reductions in CSO volume result from the conversion of larger areas to pervious land use.

The frequency of CSO events is estimated to be reduced from the baseline value of 3.1 CSO events per year to 2.9 CSO events per year in the 400-acre case. The simulated volume and number of CSO events in any particular year vary widely, depending on the size and number of large hydrologic events in each year. The results of the long-term simulations indicate the overall impact of green infrastructure averaged over many decades but do not indicate the level of CSO reduction that should be expected in each and every year.

There is a reduction in the average annual CSO volume because the pervious area increases in the CSSA, but there is no change in the SSO volume in the MACRO model results because the model parameters for the separate sewer area are unchanged from the baseline condition (the focus of this analysis was on the CSSA).
Figure 2-1 is a graphical presentation of the results in Table 2-2 for the baseline and green infrastructure cases showing the average annual CSO volume (using the scale on the left axis) and the frequency of CSO events (using the scale on the right axis).

Table 2-2. Pervious Area in the CSSA and MACRO Long Term Simulation Results.

	Baseline	**Green infrastructure conversion to pervious area**		
		+400 acres	**+1000 acres**	**+2000 acres**
CSSA (acres)	14,838	14,838	14,838	14,838
Impervious (acres)	10,725	10,314	9,697	8,668
Pervious (acres)	4,113	4,525	5,142	6,170
MACRO simulation results (64.5-year long-term simulation period, January 1940 to June 2004)				
Average annual total volume generated in the CSSA in dry and wet weather (MG/yr)	23,289	23,009	22,577	21,860
percent reduction	*0%*	*1%*	*3%*	*6%*
Average annual volume of wet weather flow generated in the CSSA (MG/yr)	12,352	12,072	11,640	10,923
percent reduction	0%	*2%*	*6%*	*12%*
Average annual volume pumped from ISS to JIWRF and SSWRF (MG/yr)	4,638	4,466	4,200	3,758
Average annual CSO volume (MG/yr)	**771**	**717**	**637**	**519**
Average annual total overflow volume (*percent reduction*)	*0%*	7%	*17%*	*33%*
Average annual CSO frequency (events/yr)	**3.1**	**2.9**	**2.7**	**2.2**
Average annual CSO frequency (*percent reduction*)	*0%*	6%	*13%*	*29%*

Notes:
1) The model parameters for the separate sewer area were unchanged from the baseline condition because the focus of the MACRO analysis was on the CSSA

CSSA = Combined Sewer Service Area
MG = Million Gallons
yr = Year
ISS = Inline Storage System
JIWRF = Jones Island Water Reclamation Facility
SSWRF = South Shore Water Reclamation Facility
CSO = Combined Sewer Overflow

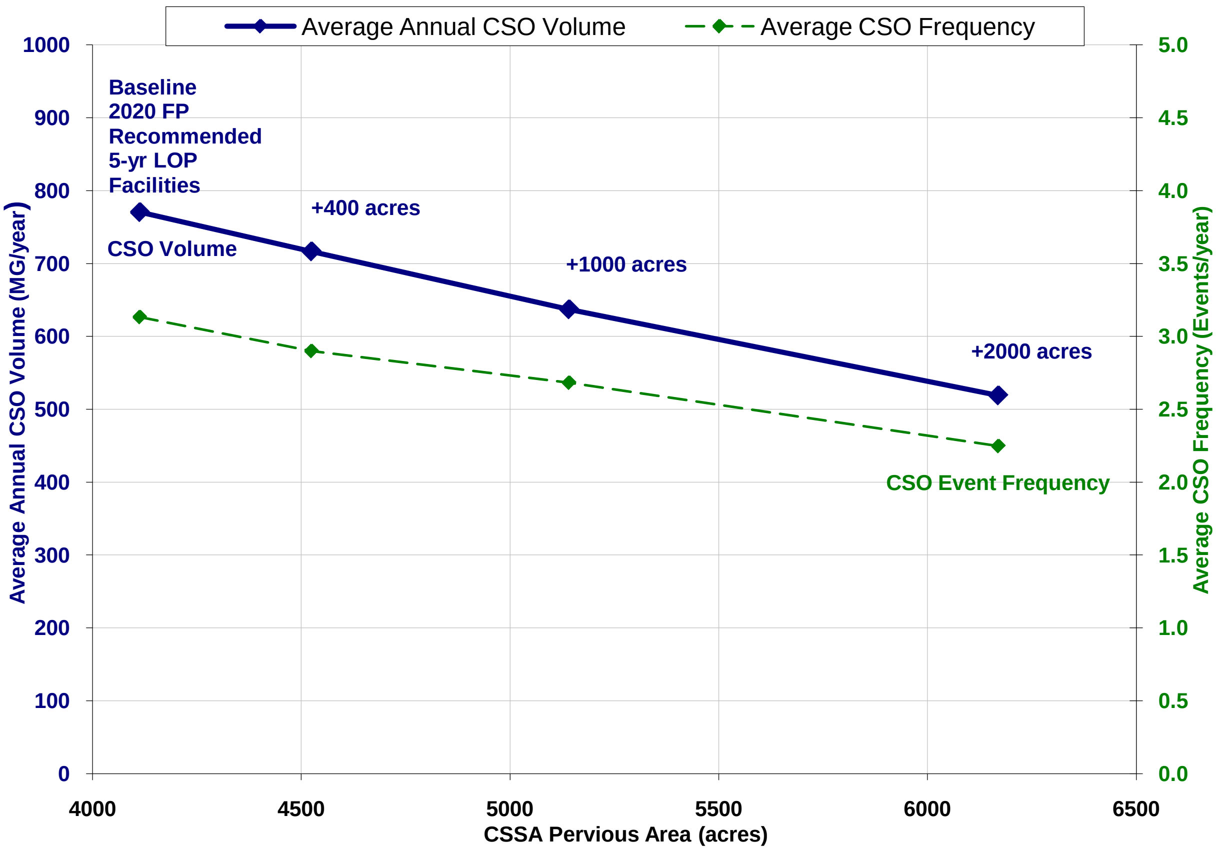


Figure 2-1. Average Annual CSO Volume and Frequency Based on Long-Term Simulations.

2.3 Specific Event Analysis

The long-term simulation analysis presented above shows the benefit of green infrastructure to reduce average CSO volume and average frequency. This section presents the reduction in simulated CSO for two specific events in response to the assumed implementation of green infrastructure. The case with an additional 400 acres is compared to the baseline case for the July 2000 event and the June 2001 event.

In the two simulations, the configuration of the MACRO model represents year 2000 population and land use with facilities and operational settings that were in place at the times of the events (2000 and 2001). Therefore, these simulations do not have the recommended facilities that were included in the long-term simulations above.

The July 2000 event had 4.4 inches of rain in 6 hours. The rainfall recurrence interval for this depth and duration is greater than 50 years, which means that this type of rainfall has approximately a 2 percent probability of occurring in any year. The short duration, high intensity rainfall of the July 2000 event produced a very large simulated CSO volume on the order of 1,000 MG.

The June 2001 event had 1.75 inches of rain in 12 hours. The rainfall recurrence interval is much less than 2 years (the SEWRPC depth, duration, frequency curves do not define recurrence intervals less than 2 years). This type of rainfall event is moderate in size and is likely to occur in any year. The June 2001 event had a moderately sized simulated CSO on the order of 100 MG. (The actual, historical CSO for the June 2001 event was also estimated to be approximately 100 MG.)

The rainfall analysis of the July 2000 and June 2001 events are summarized in Figure 2-2 in which the event rainfall depths are aggregated for several durations and compared to the depth-duration-frequency curves published by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) in *Technical Report 40* and in *Newsletter 42*, Volume No. 1, Table 1.

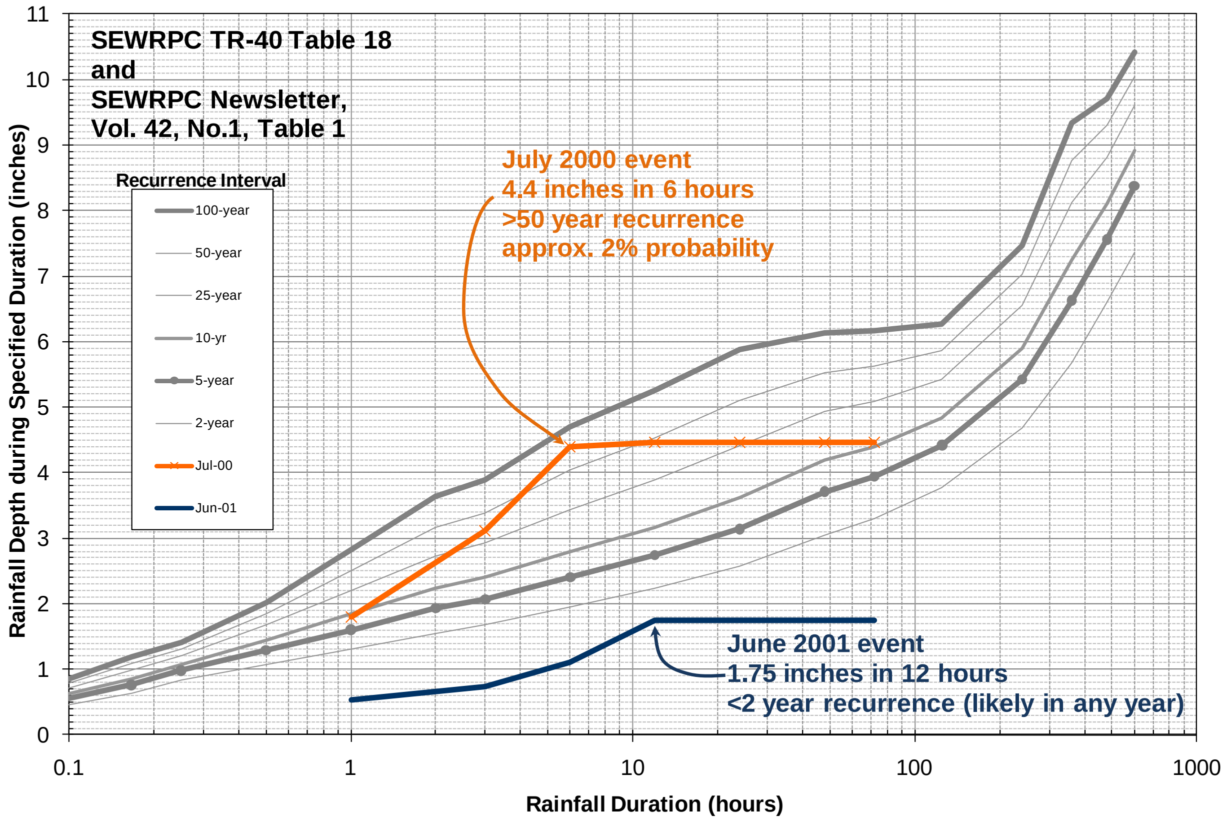


Figure 2-2. Rainfall Depth, Duration, and Frequency of the July 2000 and June 2001 Events.

MACRO simulations of the July 2000 and the June 2001 events were set up with operational parameters based on the actual operating conditions during the events. The simulations also used values for the Volume Reserved for Separate Sewer Inflow (VRSSI) that was the actual VRSSI values in use during the historical events (75 MG in 2000 and 150 MG in 2001). The MACRO model is not sufficiently detailed to simulate all of the hydraulic factors of a historical event, but the simulated overflow volumes are of the correct order of magnitude even though the simulated results are not identical to the historical, estimated overflow volumes. The model is suitable to evaluate the relative changes in CSO volume and frequency that result from changes in the input parameters that represent the implementation of green infrastructure.

Table 2-3 summarizes the operational parameters used in the simulations of the July 2000 and the June 2001 events. Table 2-4 summarizes the simulation results of the baseline case and the case with an additional 400 acres of pervious area in the CSSA.

Table 2-3. Operational Parameters for Two Specific Events.

Parameter	July 2000 Event	June 2001 Event
ISS volume	405 MG	405 MG
VRSSI	75 MG	150 MG
Jones Island peak capacity	360 MGD	360 MGD
South Shore peak capacity	300 MGD	300 MGD
ISS pump out limit to Jones Island	120 MGD	120 MGD
ISS pump out limit to South Shore	0	0
Population and land use conditions	Year 2000	Year 2000
Meteorological inputs source	July 1-7, 2000 GMIA rainfall	June 11-16, 2001 GMIA rainfall
Rainfall description	4.4 inches in 6 hours Greater than 50-year recurrence *Large rain event with approximately 2% probability of occurrence in any year.*	1.75 inches in 12 hours Much less than 2-year recurrence *Typical rainfall event with a magnitude that is likely in any year.*

ISS = Inline Storage System
MG = Million Gallons
GMIA = General Mitchell International Airport
VRSSI = Volume Reserved for Separate Sewer Inflow
MGD = Million Gallons per Day

Table 2-4. MACRO Simulation Results for Two Specific Events.

	July 2000 Event			June 2001 Event		
	Baseline	Green Infra +400 acres pervious	Percent reduction	Baseline	Green Infra +400 acres pervious	Percent reduction
Total wastewater volume generated in CSSA	1,610 MG	1,587 MG	1%	554 MG	537 MG	3%
Reduction of total wastewater volume generated in CSSA (baseline vs. +400 acres pervious)	--	23 MG	--	--	17 MG	--
Simulated CSO volume	1,132 MG	1,108 MG	2%	102 MG	84 MG	18%
Reduction of simulated CSO volume (baseline vs. +400 acres Pervious)	--	24 MG	--	--	18 MG	--
Percent CSSA volume captured and treated	30%	30%	0%	82%	84%	2%
Peak CSO discharge rate	17,760 MGD	17,700 MGD	0%	1,350 MGD	985 MGD	27%

CSSA = Combined Sewer Service Area
MG = Million Gallons
CSO = Combined Sewer Overflow
VRSSI = Volume Reserved for Separate Sewer Inflow
MGD = Million Gallons per Day

2.3.1 Simulated July 2000 Event

In the baseline case the CSSA generated 1,610 MG of simulated wastewater in the July 2000 event. The large peak flow rates and the large volume generated in the CSSA exceeded the treatment capacity of the Jones Island WRF and the allocated storage volume of the ISS; therefore, excess combined sewage overflowed with a simulated volume of 1,132 MG and a peak overflow rate of 17,760 MGD. In spite of the extreme magnitude of the event, 30 percent of the combined sewage generated in the CSSA was successfully treated and the excess was bypassed.

The simulation results for the case with 400 acres of additional pervious area reduced the volume generated by 23 MG, which resulted in a similar reduction in overflow volume (a 2 percent reduction in total CSO volume). In the

400-acre case, approximately 30 percent of the wastewater volume was captured; thus, the percent captured value is the same for the baseline and for the 400-acre case.

Figure 2-3 is a time series plot of the July 2000 event simulation. The figure shows the flow rate at the Jones Island WRF (using the scale on the left axis), the volume of wastewater stored in the ISS (also using the scale on the left axis), and the CSO discharge rate (using the scale on the right axis). The runoff from the CSSA produces a very fast rise in flow at the Jones Island WRF and a very fast increase in the volume stored in the ISS. When the volume in the ISS was approximately 330 MG, the gates to the ISS from the CSSA were closed to reserve the remaining ISS volume for excess wastewater from the separate sewer area. The ISS did not fill completely (a maximum volume of 379 MG out of the 405 MG total ISS volume); therefore, no tunnel-related SSO resulted from the July 2000 event in spite of the high intensity of the rainfall. The CSO discharge started immediately upon the closure of the ISS gates to the CSSA and continued for five hours. The peak overflow rate was almost 18,000 MGD with a total volume of approximately 1,100 MG.

Figure 2-3 shows the simulation results for both the baseline case and the 400 acre additional pervious area case; however, the results are almost identical and cannot be easily distinguished in the figure. The curves for the baseline case are lighter weight dotted lines, which are over-scribed by the solid lines for the results of the 400-acre case.

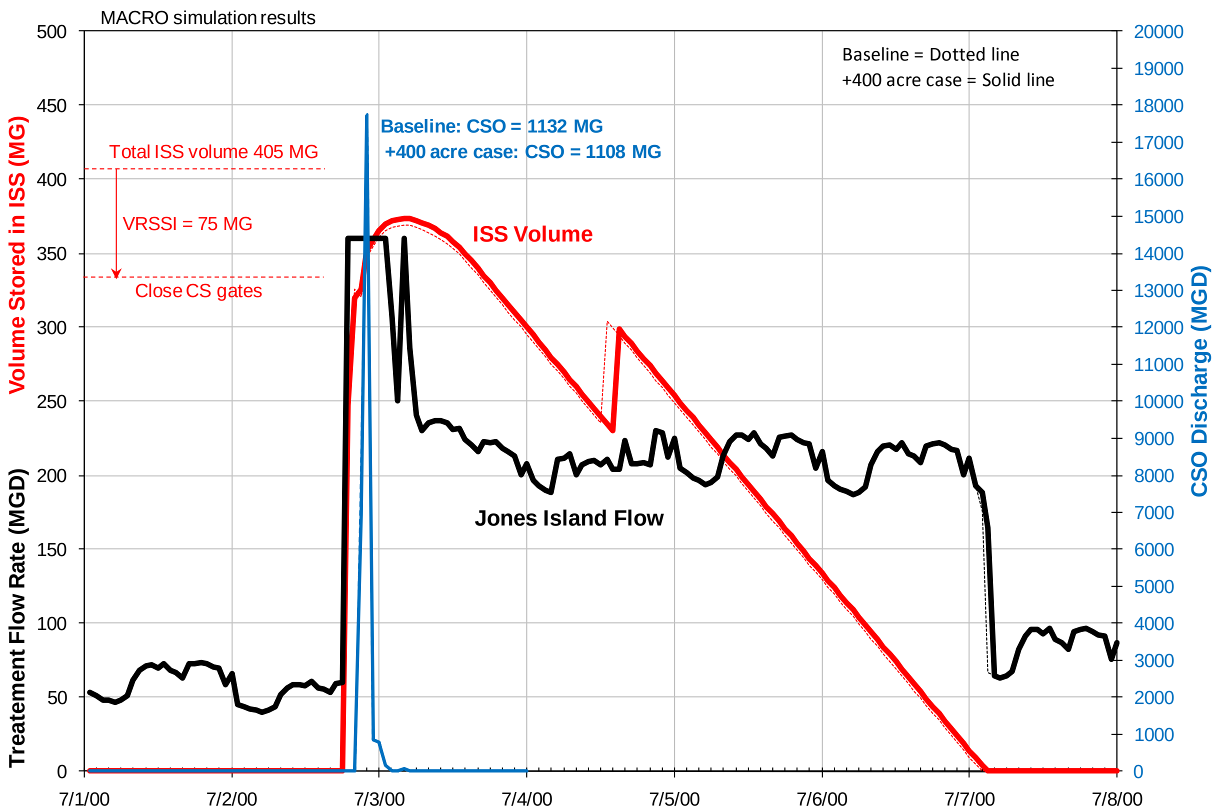


Figure 2-3. MACRO Simulation Results, July 2000 Event.

2.3.2 Simulated June 2001 Event

In the baseline case the CSSA generated an estimated 554 MG of simulated wastewater in the June 2001 event. The peak flow rates and the volumes in the June 2001 event were much less than the July 2000 event, but still exceeded the treatment capacity of the Jones Island WRF and the allocated storage volume of the ISS. The simulated CSO volume was 102 MG in the baseline case, with a peak overflow rate of 1,350 MGD. Because of the moderate magnitude of the event, 82 percent of the combined sewage generated in the CSSA was successfully treated.

The 400-acre case produced 84 MG of CSO, thus 84 percent of the wastewater was captured and treated. The reduction in CSO volume by the 400-acre case is similar in both of the events (27 MG of CSO removed by green infrastructure in the large July 2000 event and 18 MG of CSO removed in the moderate June 2001 event). The percent reduction in CSO volume is more significant in the moderate June 2001 event in which the CSO was reduced 18 percent. The CSO reduction in the larger July 2000 event is only 2 percent.

Figure 2-4 is a time series plot of the June 2001 event simulation. Even for a moderate event such as this one, the runoff from the CSSA produces a fast rise in flow at the Jones Island WRF and a rapid increase in the volume stored in the ISS. When the volume in the ISS was approximately 255 MG, the gates to the ISS from the CSSA were closed. The CSO discharge started immediately upon the closure of the ISS gates to the CSSA and continued for 3 hours. The ISS did not fill any further after the CSSA gates were closed because all of the flow from the separate sewer area was successfully treated at the WRFs (no tunnel-related SSO).

Figure 2-4 shows the simulation results for both the baseline case and the 400-acre case; however, the responses are almost identical. In the CSO discharge curves, the baseline case peaked at 1350 MGD and the 400-acre case peaked at 985 MGD.

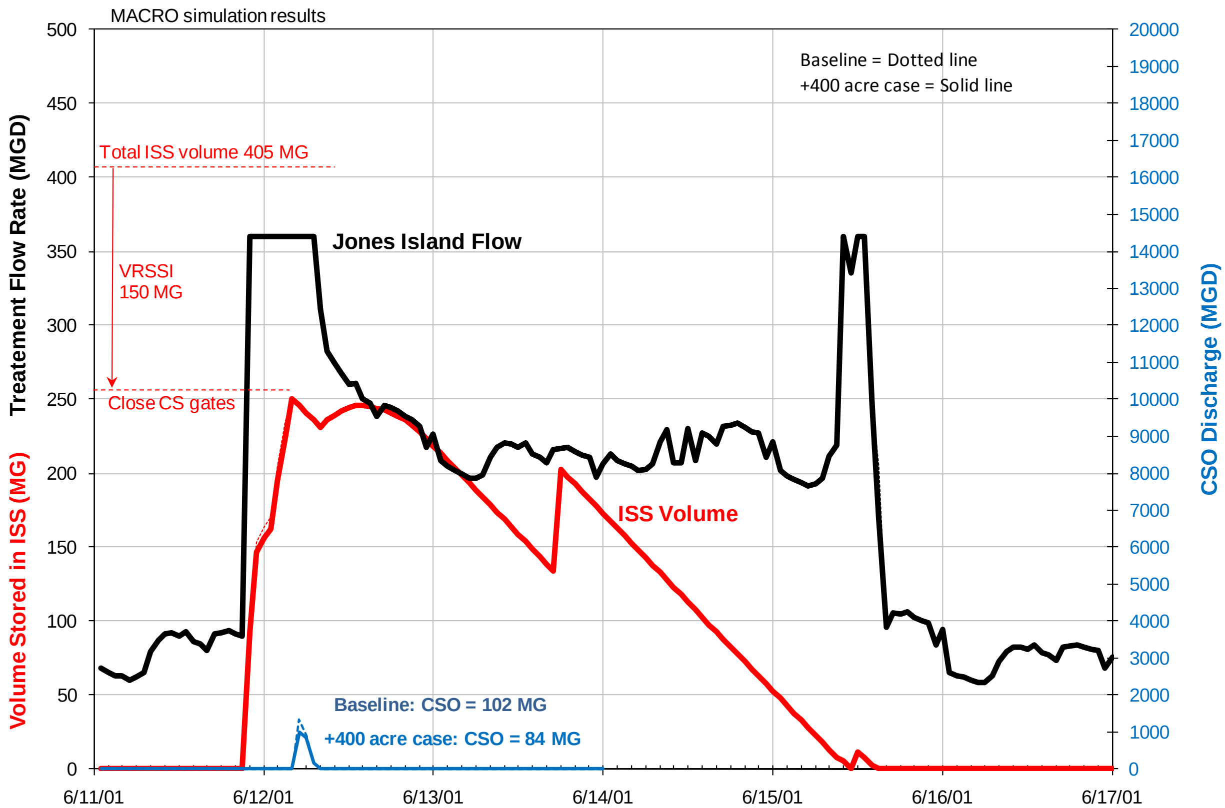


Figure 2-4. MACRO Simulation Results, June 2001 Event.

2.4 Summary of Screening Level Analysis

The conversion of impervious areas to pervious land surface areas by the implementation of green infrastructure results in less CSO volume and reduced frequency of CSO events in the long-term MACRO model simulations. There is no simulated change in SSO response because all of the model changes are in the CSSA.

Very small wet weather events demonstrate the most noticeable percent CSO reduction. The cumulative benefit of many small wet weather events is the source of the overall reduction in CSO volume and frequency. For larger wet weather events, such as the examples shown for July 2000 and June 2001, the absolute value of the CSO reduction is of the same order of magnitude, but the percent reduction is small relative to the large volume of CSO.

The MACRO model is a screening level model that is useful to evaluate the overall response of the MMSD conveyance system. The results of the model should be used to estimate the approximate change in the system-wide performance in response to the conversion of impervious areas into pervious areas. The model is not intended to be used to predict the impact of changes in small localized project areas.

3 Detailed Optimization Analysis within a Pilot Area of the Combined Sewer Service Area

The analysis conducted with the MACRO model confirms the potential of green infrastructure to have a significant impact on average annual CSO volumes and events in Milwaukee. However, the model is limited in its ability to fully simulate the potential hydrologic and water quality benefits of green infrastructure. For example, representing green infrastructure simply as the conversion of impervious areas to pervious areas does not account for the potential to route runoff from impervious areas to new green infrastructure. In addition, it does not fully simulate the processes associated with different green infrastructure practices (i.e., increased evapotranspiration provided by bioretention, infiltration rates above natural background due to placement of underdrains). The SUSTAIN model was therefore applied to a pilot area within the Combined Sewer Service Area (CSSA) to allow for a more detailed analysis and to determine the most cost-effective set of green infrastructure practices for runoff volume reduction. The SUSTAIN modeling was applied after the initial MACRO modeling described in Section 2, and the results from the SUSTAIN modeling were then used to inform a fourth run of the MACRO model, presented in Section 3.7. Impacts to CSOs were also estimated for the entire CSSA.

3.1 Description of SUSTAIN

SUSTAIN is a model developed by the U.S. Environmental Protection Agency (USEPA) to evaluate alternative plans for water quality management and flow abatement techniques in urban areas. The development of SUSTAIN represents an intensive effort to create a tool for evaluating, selecting, and placing green infrastructure practices in an urban watershed on the basis of user-defined cost and effectiveness criteria. SUSTAIN provides a public domain tool capable of evaluating the optimal location, type, and cost of stormwater green infrastructure practices needed to meet water quality goals. It is a tool designed to provide critically needed support to watershed practitioners at all levels in developing stormwater management evaluations and cost optimizations to meet their existing program needs.

SUSTAIN incorporates the best available research that could be practically applied to decision making, including the tested algorithms from the Storm Water Management Model (SWMM), the Hydrologic Simulation Program in Fortran (HSPF) model, and other green infrastructure practice modeling techniques. Linking those methods into a seamless system provides a balance between computational complexity and practical problem solving. The modular approach used in SUSTAIN also facilitates updates as new solutions become available.

A key feature of the SUSTAIN model is its ability to evaluate numerous potential combinations of green infrastructure practices to determine the optimal combination that meets a pre-specified objective. For example, Figure 3-1 portrays a SUSTAIN cost-effectiveness curve that evaluates different sets of practices to achieve a reduction in peak stream flow.

Each of the hundreds of circles within this curve represents a separate modeling run scenario with different assumptions for the number, type, and characteristics of practices. One scenario includes the use of only 1,000 rain barrels, another includes the use of 300 rain barrels and 200 rain gardens, and a third scenario includes a combination of 200 rain barrels, 200 rain gardens, 5,000 square feet of green roofs, and 2 detention ponds. Still other scenarios include different assumptions for the size of the practices (e.g., 50 gallon rain barrels compared to 60 gallon rain barrels).

The model simulates the ability of each of these practices individually, and in combination, to reduce peak stream flows, taking into account the site-specific characteristics of the project area (e.g., soil types, land uses, precipitation patterns). Practitioners can specify scenarios with specific practices (e.g., a stormwater wetland at given location), nonspecific practices (e.g., *X* number of houses on a given city block have rain gardens of *Y* storage volume) or both. Sophisticated modeling algorithms are used to compute infiltration, evapotranspiration, and runoff, as well as pollutant loading. Calculations are made at an hourly scale over a multi-year period to provide a full assessment of the response to each individual storm. At the same time, SUSTAIN assigns a locally-derived cost to each practice to achieve a total cost for each scenario.

Plotting the combination of effectiveness and total cost for each of the hundreds of model runs results in the graph shown in Figure 3-1. The set of solutions at the far left and far top creates a cost-effectiveness curve. Planners and decision makers should select their solution from this curve because they could obtain a better result at the same cost. As shown by the arrows in Figure 3-1, the curve also allows planners and decision makers to determine the best set of practices based on either (a) a given peak stream flow reduction target or (b) a set budget. The curve may also identify points of diminishing returns across a range of costs. Similar cost effectiveness curves can be created for other objectives, such as runoff volume or pollutant loading reductions.

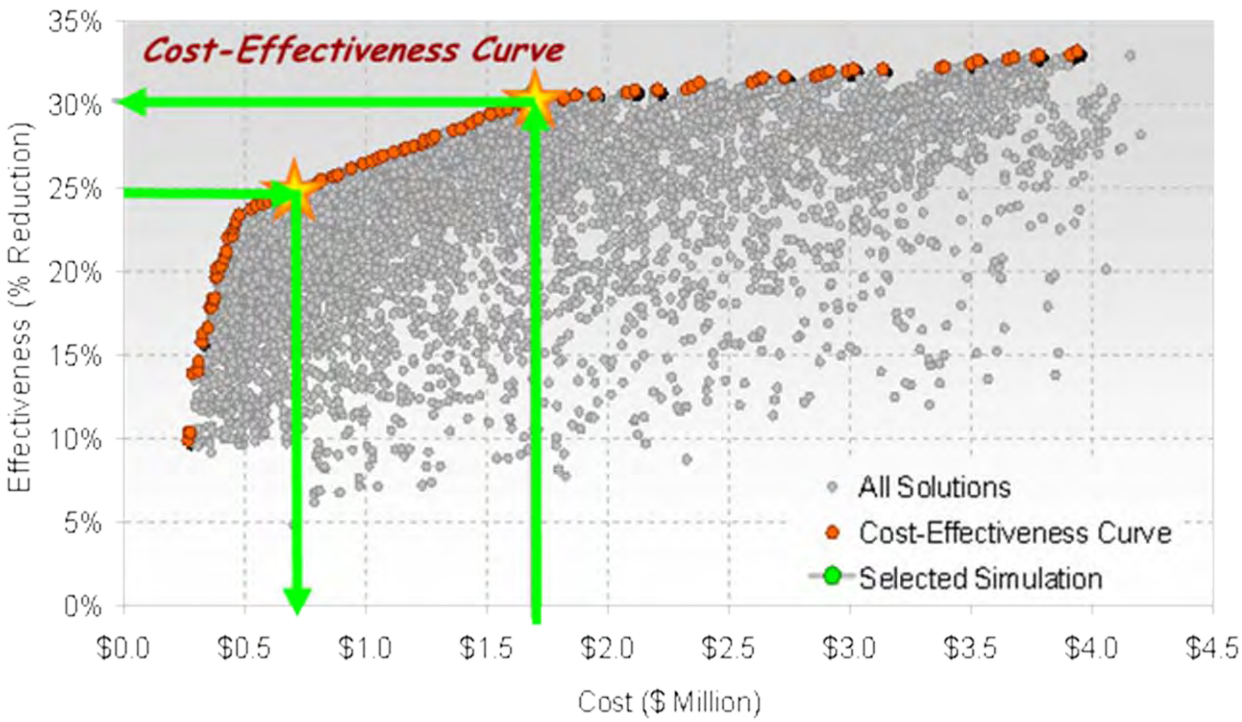


Figure 3-1. Example SUSTAIN Cost-effectiveness Curve.

SUSTAIN includes the following components (USEPA 2009a):

- Framework Manager—to serve as the command module of SUSTAIN, manage data for system functions, provide linkages between the system modules, and create a simulation network to guide the modeling and optimization activities
- Land module—to generate runoff and pollutant loads from the landscape through internal land simulation or importing pre-calibrated land simulation time series
- Best Management Practice (BMP) module—to perform simulation of flow and water quality through green infrastructure practices, accounting for specific design criteria, and hydrologic/hydraulic processes
- Conveyance module—to perform routing of flow and water quality in a pipe or a channel
- Optimization module—to evaluate and identify cost-effective green infrastructure placement and selection strategies for a preselected list of potential sites, applicable green infrastructure types, and ranges of practice size
- Post-Processor—to perform analysis and summarization of the simulation results for decision making

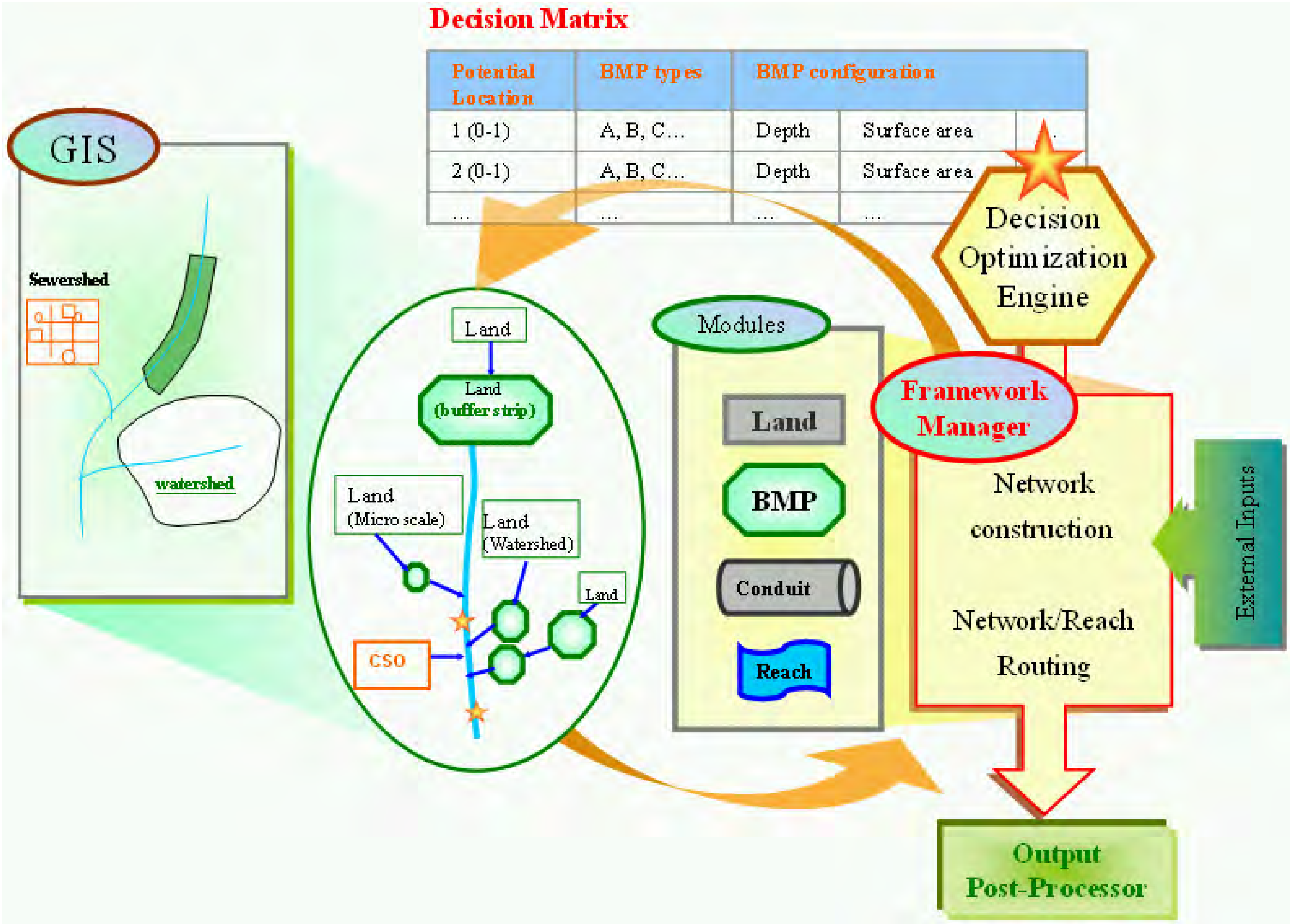


Figure 3-2. SUSTAIN Components and Flow Chart.

Figure 3-2 shows the framework design, including system components, relationships between components, and the general flow of information. Setting up a SUSTAIN project involves using locally collected data to establish a representation of the land and pollutant sources in the watershed, the routing network, assessment points, evaluation factors, and management practices to be evaluated.

After project setup, the optimization module synthesizes information from the BMP, land, and conveyance modules and generates solutions that are looped back for evaluation using the same modules again. Via this search process, the optimizer identifies the best or most cost-effective solutions according to the user's specific conditions and objectives.

Finally, the post-processor analyzes optimization results using specific graphical and tabular reports that facilitate the classification of storm events for analysis, viewing the time series of specific storm events, evaluating performance by storm event, and developing the cost-effectiveness curves for treatment alternatives.

3.2 Description of the Pilot Area

Three sewersheds south of Capitol Drive and west of the Milwaukee River were chosen for the pilot SUSTAIN evaluation (Figure 3-3). These sewersheds were chosen because they are considered representative of the entire CSSA in terms of soil conditions, topography, etc., and because they include a mix of residential, commercial, industrial, and transportation areas to which a variety of green infrastructure practices are applicable. The following sections provide a more detailed description of each individual sewershed and Figure 3-4 illustrates the existing land uses. Representative photographs of the pilot area are shown in Figure 3-5.

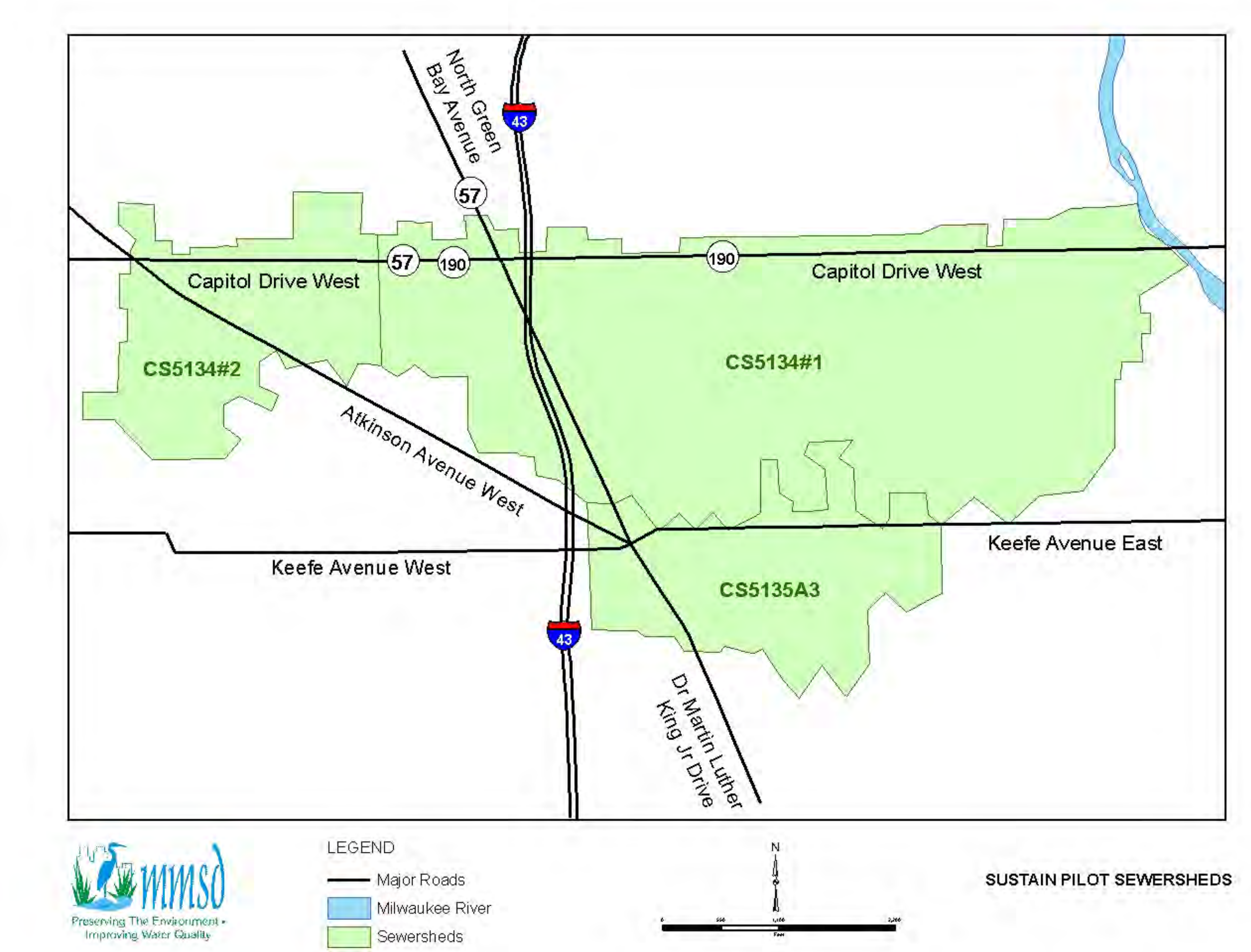


Figure 3-3. Location of SUSTAIN Pilot Sewersheds.

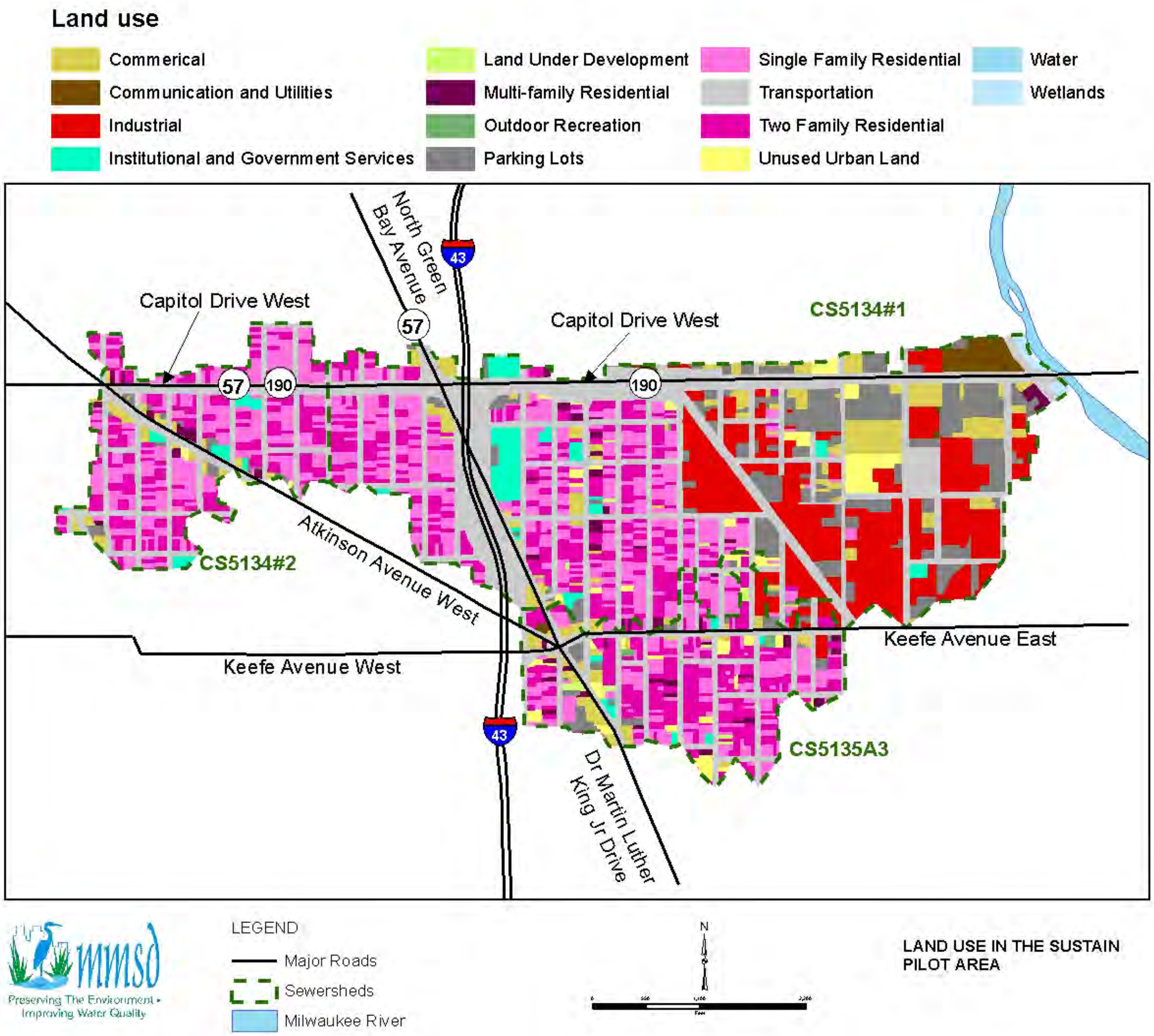


Figure 3-4. Land Use in the SUSTAIN Pilot Area.

Figure 3-5. Representative Photos in the Study Area.

3.2.1 Sewershed CS5134 #2

The CS5134 #2 sewershed is predominantly residential with commercial and multi- family residential land uses along Capitol Drive and Atkinson Avenue West (Table 3-1 and Figure 3-4). The residential area is characterized by either single family or two-family residences served by local streets and alleys (Figure 3-6). Sidewalks are on both sides of the street and homes are set close to these sidewalks, resulting in small front yards. Backyards are also small, typically containing a detached garage served by a rear yard alley. Boulevard trees line many of the local streets and the streets are typically 26 to 32 feet wide.

Commercial properties and apartment complexes are common along Atkinson Avenue West. These properties are served by parking lots of various dimensions.

There are very few vacant or undeveloped areas within this sewershed.

Table 3-1. Sewershed CS5134 #2 Land Use

Land use	Area (acres)	Area (% of total)
Commercial	3.6	4%
Communication and utilities	-	-
Industrial	-	-
Institutional and government services	2.5	2%
Land under development	-	-
Multi-family residential	1.6	2%
Outdoor recreation	-	-
Parking Lots	2.2	2%
Single family residential	33.8	34%
Transportation	32.6	32%
Two family residential	24.2	24%
Unused urban land	0.3	< 1%
Water	-	-
Wetlands	-	-
Total	**100.8**	**100%**

Figure 3-6. Typical Residential Lot in Sewershed CS5134 #2.

3.2.2 Sewershed CS5135A3

The CS5135A3 sewershed is predominantly residential (Table 3-2 and Figure 3-4). The residential areas are similar to those described in sewershed CS5134#2. This sewershed has a significant amount of green space in the form of vacant and double lots. Local streets are typically 26 to 32 feet wide.

There are commercial and multi-family properties concentrated along Dr. Martin Luther King Jr. Drive and along Keefe Avenue within this sewershed. A few industrial parcels are located in the northeast corner of this sewershed.

Table 3-2. Sewershed CS5135A3 Land Use.

Land use	Area (acres)	Area (% of total)
Commercial	5.7	5%
Communication and utilities	0.3	< 1%
Industrial	2.9	3%
Institutional and government Services	1.3	1%
Land under development	1.3	1%
Multi-family residential	3.3	3%
Outdoor recreation	0.5	1%
Parking lots	5.0	5%
Single family residential	20.5	20%
Transportation	30.3	29%
Two family residential	29.1	28%
Unused urban land	4.6	4%
Water	-	-
Wetlands	-	-
Total	**104.8**	**100%**

3.2.3 Sewershed CS5134 #1

Land uses within the CS5134 #1 sewershed consist of residential, large transportation corridors, and a mix of commercial and industrial areas (Table 3-3 and Figure 3-4). The residential area is similar to sewershed CS5134 #2 and CS5135A3. Local residential streets are typically 26 to 32 feet wide. There is a large school facility located along North Green Bay Avenue and a railroad that bisects the sewershed within the mixed commercial and industrial area. This sewershed extends to the Milwaukee River in the east.

Commercial properties are typical in the eastern half of the sewershed and along the larger collector streets. Many of these properties have large flat roofs and very large parking lots.

There are several large undeveloped areas within the industrial/commercial area of the sewershed and many small undeveloped or vacant lots within the residential area. In addition, green space located adjacent to the freeway and larger streets provides for opportunity to install green infrastructure practices.

Table 3-3. Sewershed CS5134 #1 Land Use.

Land use	Area (acres)	Area (% of total)
Commercial	24.0	6%
Communication and utilities	5.7	1%
Industrial	71.3	18%
Institutional and government services	10.1	3%
Land under development	0.6	< 1%
Multi-family residential	4.1	1%
Outdoor recreation	0.2	< 1%
Parking lots	45.5	11%
Single family residential	54.9	14%
Transportation	127.6	32%
Two family residential	42.7	11%
Unused urban land	8.0	2%
Water	0.1	< 1%
Wetlands	1.4	< 1%
Total	**396.1**	**100%**

3.3 Assessment of Green Infrastructure Opportunities

The MMSD has identified ten green infrastructure practices within its *Fresh Coast Green Solutions* publication. Ten specific practices were grouped into the following four generalized categories for application within SUSTAIN (Table 3-4):

- Bioretention (including rain gardens and bio-swales)
- Rain barrels
- Green roofs
- Porous pavement (including green alleys)

Table 3-4. MMSD and SUSTAIN Green Infrastructure Practices.

***Fresh Coast Green Solutions* practices**	**SUSTAIN practices**
Greenway	Not simulated
Rain garden	Bioretention
Wetlands	Not simulated
Stormwater trees	Assumed to be part of bioretention design
Green roofs	Green roof
Bioswales	Bioretention (adjacent to transportation corridors)
Porous pavement	Porous pavement
Native landscaping	Assumed to be part of bioretention design
Rainwater catchment	Rain barrel
Green alleys and parking lots Green streets	Porous pavement Porous pavement and bioretention

The potential for greenways and wetlands within the pilot areas are limited and were therefore not included within the analysis (although they are addressed in the TBL discussion in Section 5). Stormwater trees and native landscaping were assumed to be included as part of the bioretention areas and bioswales. Green streets were modeled as a combination of porous pavement and block bioretention. Potential green streets included Capitol Drive, Keefe Avenue, Dr. Martin Luther King Jr. Drive and Atkinson Avenue.

Each of these practices was evaluated for applicability within the three pilot sewersheds based on a review of aerial imagery. Applicability was based on available land or roof area and proximity to sources of runoff and pollutants. Applicability and green infrastructure practice specifications in the SUSTAIN model assume a mix of fill and native clay-rich soils, with a background soil infiltration rate of 0.15 inch per hour. It should be noted that actual implementation of these practices will also have to consider infiltration rules found in NR 151.12 (5)(c).

The assessment of green infrastructure opportunities also involved an analysis of various combinations of practices (i.e., treatment trains). Using a treatment train approach, stormwater management begins with simple methods that minimize the amount of runoff from a site. Typically these practices involve either on-site interception (e.g., rain barrels, green roofs) or on-site treatment (e.g., bioretention, porous pavement, infiltration trenches). Following efforts to minimize site runoff, stormwater is collected and treated either locally or regionally (e.g., block or regional bioretention).

A description of each green infrastructure practice and the considerations made during the feasibility analysis are provided in the following sections. Modeled design specifications for each practice are described under “SUSTAIN Model Setup.”

3.3.1 Bioretention

Bioretention areas were chosen to represent rain gardens and bioswales as well as a portion of the green street practice. Three different types of bioretention practices were included in the SUSTAIN model: (1) rain garden, (2) block bioretention, and (3) regional bioretention.

3.3.1.1 Rain Garden

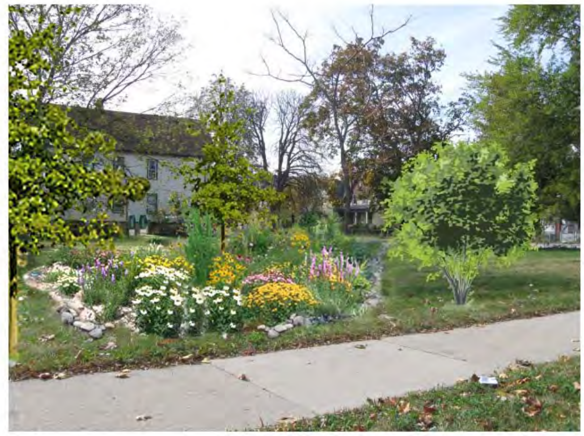
Rain gardens, or small yard bioretention areas, are modeled in SUSTAIN as an aggregate practice, which means that specific locations are not identified, but that a template is designed and applied across the entire modeling subwatershed. Rain garden areas are assumed to be located in front or back yards of residential areas and would serve the overflow from rain barrels and runoff from the surrounding area. These small bioretention areas are also assumed to be constructed and maintained by the homeowner with little costs associated with design. A soil amendment is assumed with no underdrain. Front yard size was considered when setting the upper limit on the area of these bioretention practices (50 square feet). It was assumed that a maximum of 50 percent of homes in the residential areas could be served by rain garden areas.

3.3.1.2 Block Bioretention

Block bioretention areas include larger rain gardens and a portion of the green street practice. Potential locations for block bioretention within residential areas were identified through aerial imagery analysis. Block bioretention areas are modeled in SUSTAIN as aggregate practices. The bioretention areas are assumed to have free flow perforated pipe underdrains. Drainage areas to block bioretention areas were estimated according to Table 3-5 for residential areas. These drainage areas represent the maximum amount of potential area that could be routed to block bioretention areas.

Table 3-5. Percent of Watershed Draining to Block Bioretention Areas.

Sewershed	Drainage area as percent of residential areas
CS5134#2	30%
CS5135A3	100%
CS5134 #1-E	50%
CS5134 #1-W	50%



The green street design includes both block bioretention and porous pavement (as described in the Porous Pavement section). Block bioretention is assumed to be either within medians or as curb bump-outs. It was assumed that up to 10 percent of the width of the existing roadway (4 to 9 feet in width) could be converted into block bioretention areas. The drainage area was assumed to be the entire roadway corridor, routing one-third of the drainage area directly to the block bioretention areas and two-thirds to porous pavement areas. Overflow from the porous pavement was then routed to the bock bioretention areas.

3.3.1.3 Regional Bioretention

Regional bioretention areas are the largest of the delineated bioretention areas, located in the commercial and industrial land use areas and along the transportation corridors. These areas are assumed to be rain gardens within the commercial/industrial areas or bioswales when adjacent to roadways. They are modeled in SUSTAIN assuming 24 inches of ponded depth, 24 inches of plant and soil media, and free flowing perforated pipe underdrains. SUSTAIN assumes 100 percent of the interstate and highway transportation corridor gets treated in these bioretention areas. For the commercial area, drainage areas are assumed to be equal to 30 times the area of the bioretention area, treating approximately 1 inch of runoff in the contributing watershed.

3.3.2 Green Roofs

Green roofs can typically be placed on any flat roof surface, assuming the roof can support the additional weight. Potential green roof locations were identified throughout the three sewersheds using aerial photography. It was assumed that all flat roofs would have the structural support necessary to carry a green roof, which results in an overestimation of the maximum potential area suitable for green roofs. The drainage area to green roofs is assumed to include the entire roof surface.

3.3.3 Porous Pavement

Porous pavement can be used in several applications within the pilot sewersheds. The SUSTAIN model assumes that all alleys could be converted to porous pavement as green alleys. For green alley applications, it was assumed the green alley treats runoff from the surrounding impervious area that is four times the area of the green alley. Underdrains were assumed in the green alley applications.

Parking lots were also evaluated for applicability. Parking lots were identified based on land use data provided by MMSD which was based on imagery from the year 2000. Land use data were verified and adjustments were made to the spatial data to better represent the parking lots. All parking lots are assumed to have underdrain systems. Considering the driving lanes remain asphalt or concrete while the parking spots are made permeable, only 60 percent of the parking lot area is considered permeable. The drainage area remains the entire parking lot.

A portion of each street was also evaluated for conversion to porous pavement. Local streets were identified using geographic information system (GIS) coverages and land use information and included all streets in the pilot areas with the exception of Capitol Drive, Keefe Avenue, Dr. Martin Luther King Jr. Drive and Atkinson Avenue and Interstate 43. An eight foot parking lane was assumed to be converted to porous pavement with underdrains along each local street. Road widths were assumed to be 32 feet, and the drainage area to the roadside porous pavement was assumed to be the entire roadway.

The green street practice, which includes bioretention and porous pavement components, was modeled for collector streets including Capitol Drive, Keefe Avenue, Dr. Martin Luther King Jr. Drive and Atkinson Avenue. Porous pavement with underdrains was assumed along two eight foot wide parking lanes on either side of the road in series with block bioretention areas (as described in the Bioretention section). The drainage area was assumed to be the entire roadway corridor, routing one-third of the drainage area directly to the block bioretention areas and two-thirds to the porous pavement areas. Overflow from the porous pavement was then routed to the block bioretention areas.

3.3.4 Rain Barrels

Rain barrels have a high applicability in the residential areas within all of the sewersheds. It was assumed that 50 percent of homes in the residential area may use rain barrels in sequence with rain gardens. The standard size of rain barrels in this application was 60 gallons, with a maximum of two units per home.

3.4 Maximum Extent of Practices by Sewershed

For modeling purposes, sewershed CS5134#1 was divided into two drainage areas. The division between CS5134#1-E and CS5134#1-W was made at the interface between residential neighborhoods and the large commercial / industrial land use area in the eastern part of the study area. Figure 3-7 shows the context of sewershed boundaries including the division of CS5134#1.

Based on the aerial photography analysis, the potential locations of each type of green infrastructure practice were digitized in a GIS and the results are shown in

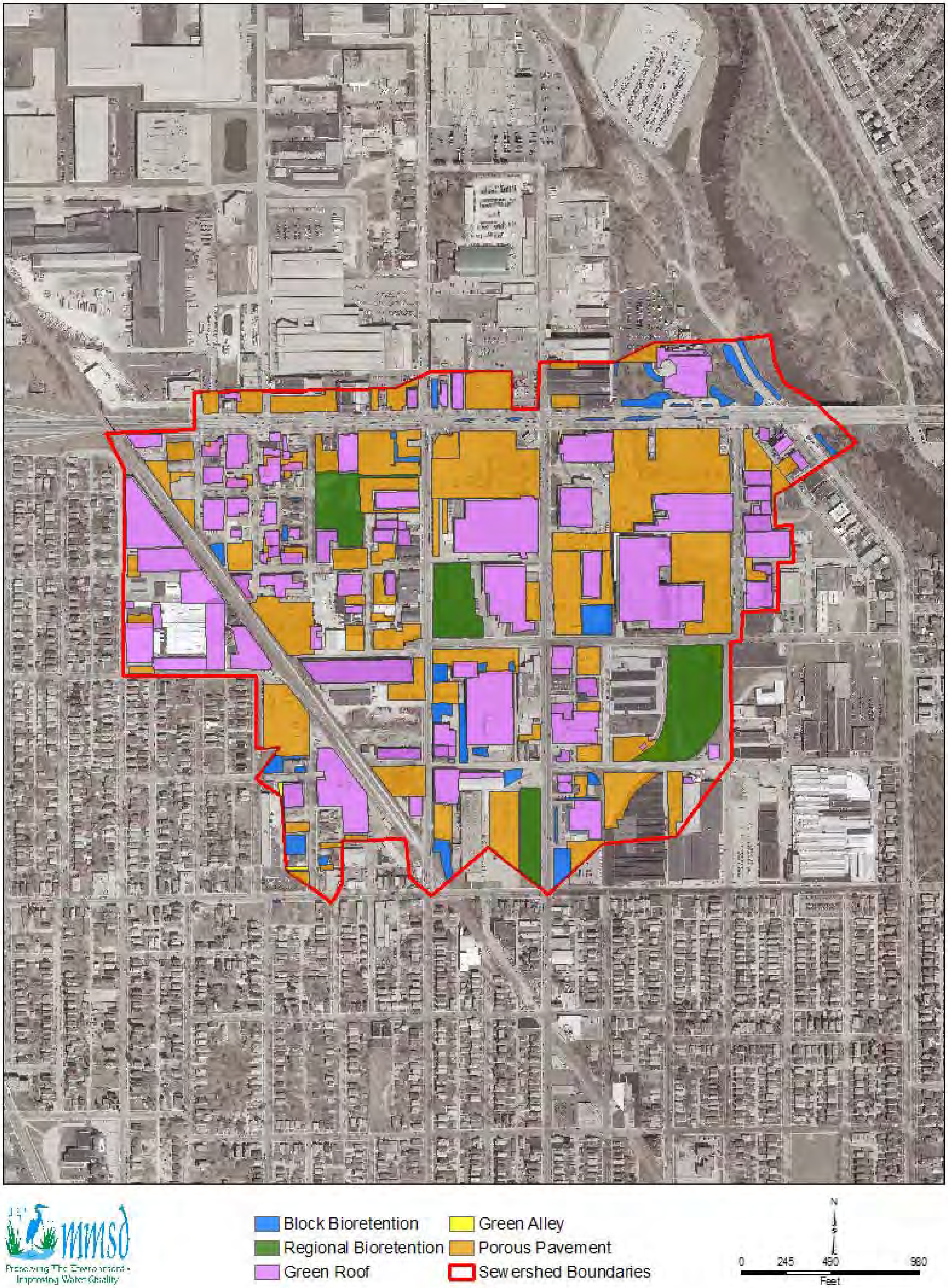


Figure 3-8 to Figure 3-11 for each of the four sewersheds. Rain gardens, rain barrels, green alleys, and roadside porous pavement were not mapped spatially. Table 3-6 summarizes the maximum extent of each practice in each sewershed. These results were used to set the maximum opportunity boundaries for green infrastructure practices in SUSTAIN.

Figure 3-7. Map of the Study Area Showing Modeled Sewershed Boundaries.

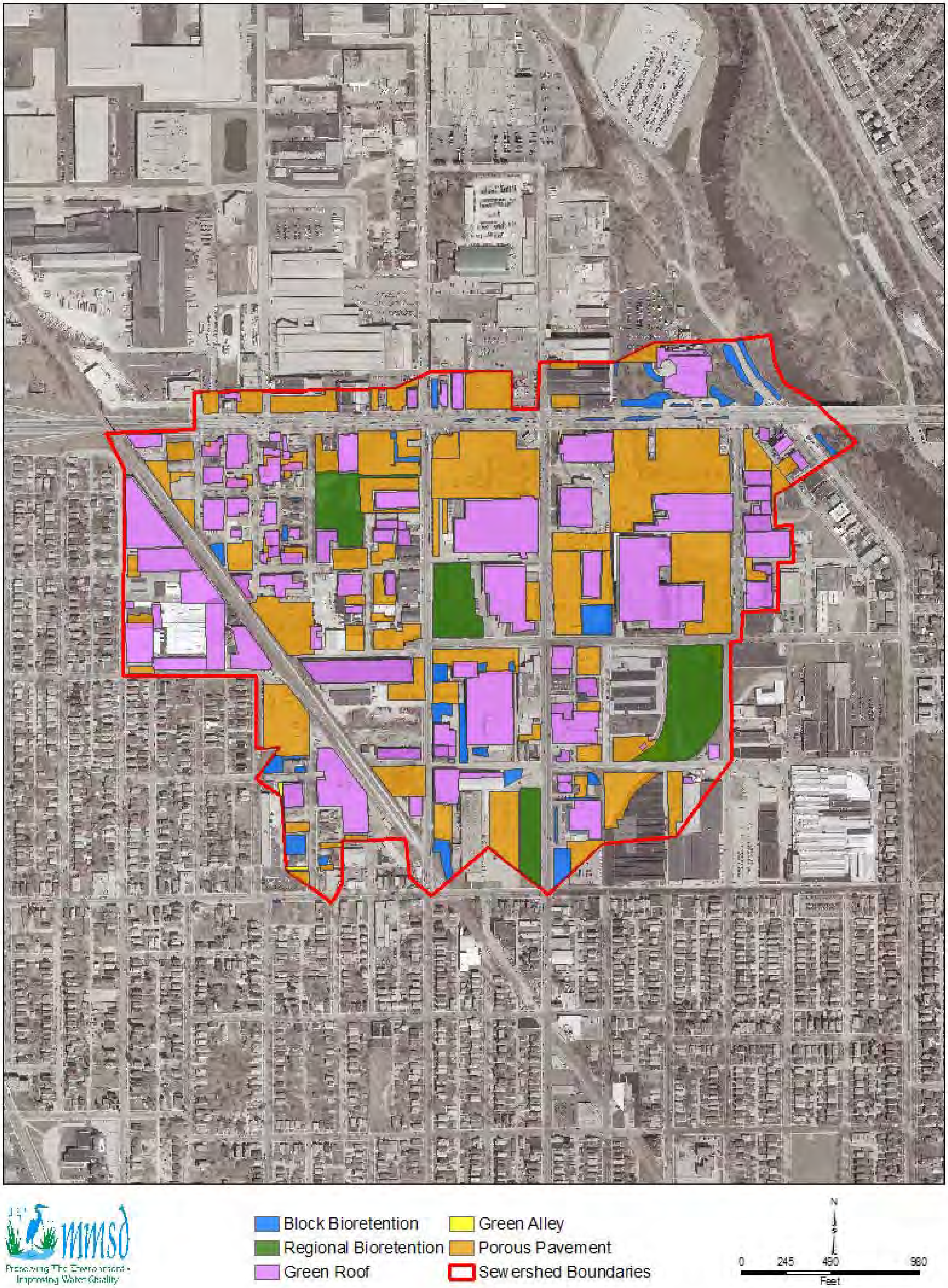


Figure 3-8. Green Infrastructure Practice Opportunities for Sewershed CS5134#1-E.

Figure 3-9. Green Infrastructure Practice Opportunities within Sewershed CS5134#1-W.

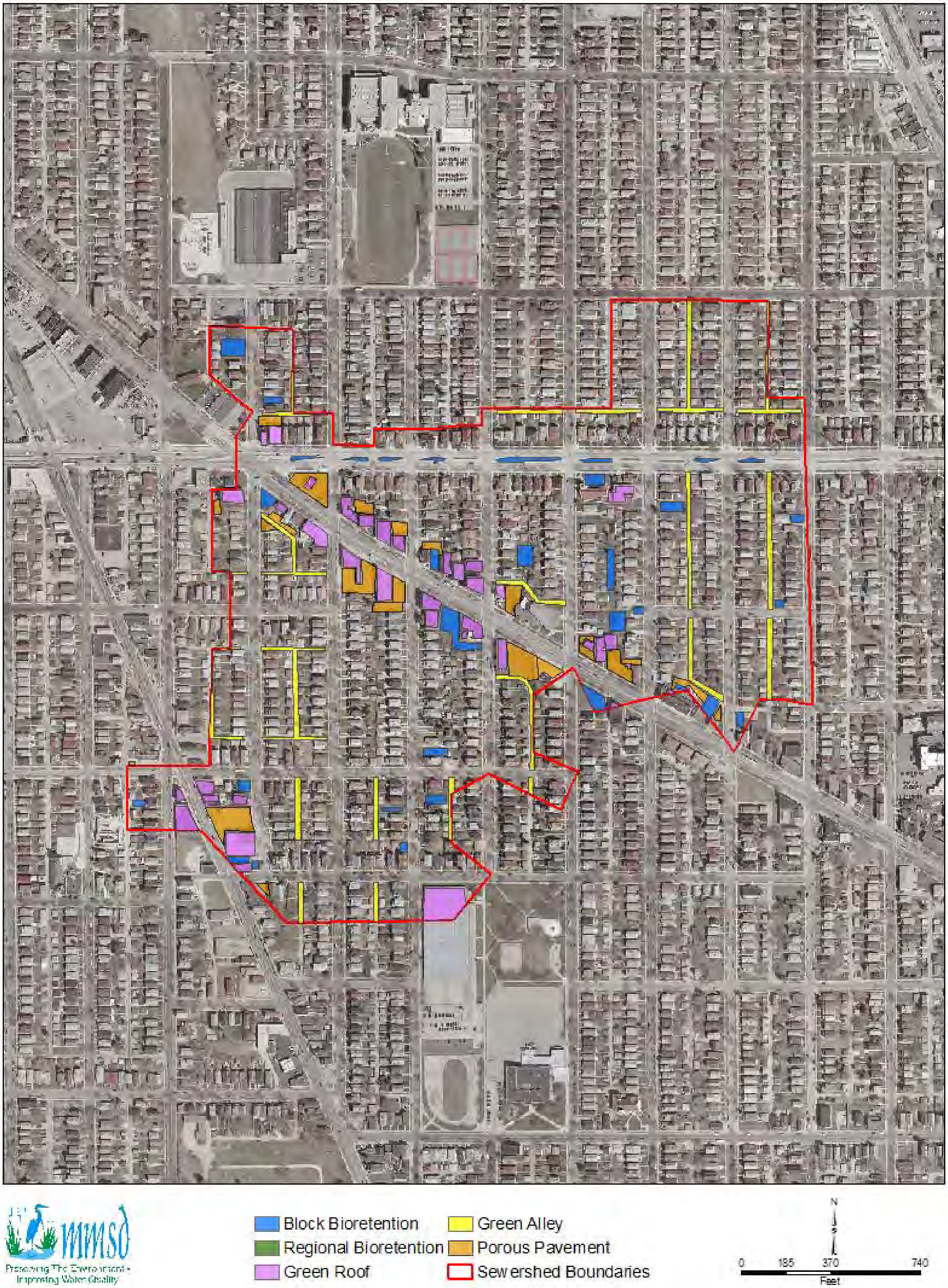


Figure 3-10. Green Infrastructure Practice Opportunities within Sewershed CS5134#2.

Figure 3-11. Green Infrastructure Practice Opportunities within Sewershed CS5135A3.

Table 3-6. Maximum Extent of Green Infrastructure Practices by Sewershed Based on Opportunity Assessment.

Green Infrastructure Practice		CS5134#2	CS5134#1-W	CS5135A3	CS5134#1-E
Porous pavement (acre)		1.7	3.3	3.3	26.9
Green alley (acre)		3.2	6.6	2.6	0.0
Block bioretention (acre)		2.2	5.8	8.9	5.2
Rain gardens (unit)		250	400	200	0
Regional bioretention (acre)		0.0	8.0	0.0	10.2
Rain barrel (unit)		500	800	400	0
Green roof (acre)		2.2	3.9	2.9	42.1
Road side porous pavement (acre)		3.4	5.9	3.1	3.7
Green street	Road side porous pavement (acre)	1.6	2.6	2.0	1.3
	Rain garden (acre)	0.7	1.3	0.6	0.7

3.5 SUSTAIN Model Setup

This section provides a description of how the SUSTAIN model was set up to simulate green infrastructure in the pilot area.

3.5.1 Model Input

The data collection process for a SUSTAIN application is similar to that of other modeling projects and involves a thorough compilation and review of information available for the study area. The more site-specific and detailed the available data, the better the model representation. The application development process includes gathering GIS data layers, including conveyance system networks, land use data, critical source information, and monitoring data for calibration and validation.

3.5.1.1 GIS Data Layers

The following GIS layers were collected and used for setting up SUSTAIN:

- Sewershed boundary clipped from the MMSD sewershed layer.
- Pipelines and manhole data layers.
- Land use raster with 1 foot cell size. The raster was generated using SEWRPC land use data, based on circa 2000 imagery.
- Land use lookup table providing the link between land use raster ID and land use name and description.
- Potential green infrastructure practice footprint shape file through review of aerial photography (see previous section).

3.5.1.2 Watershed Representation – Land Use Time Series

In 2009, MMSD developed a set of watershed, sewer, and lake models that were used to develop management plans for the year 2020. This suite of models spanned a 900 mi^2 drainage area, and integrated CSO and SSO model outflows within the larger stream network. The watershed models used in support of MMSD's 2020 Facilities Plan were the HSPF model and the Loading Simulation Program in C++ (LSPC) model[1]. Following setup, these models were extensively calibrated and validated and then used to simulate a variety of pollutants such as sediment, nitrogen, and phosphorus, among others.

[1] LSPC is a version of the HSPF model that has been ported to the C++ programming language to improve efficiency and flexibility. LSPC's algorithms are identical to a subset of those in the HSPF model. It is currently maintained by the EPA Office of Research and Development in Athens, Georgia.

For consistency with model hydrology representation in the combined sewer area, parameters for pervious and impervious land hydrology used for the MACRO model were directly mapped to LSPC pervious and impervious land uses to be used by SUSTAIN. Water quality parameters from the MMSD LSPC watershed models were also mapped as shown in Table 3-7 so that water quality benefits could be evaluated in SUSTAIN (water quality within the CSSA is not modeled by MACRO).

Table 3-7. HSPF, LSPC, and SUSTAIN Model Parameter Mapping by Land Use.

LSPC/SUSTAIN Land Use File	HSPF Parameter Mapping Used As Input to MACRO	LSPC Parameter Mapping (by Land Use) Used in SUSTAIN
1.out	PERLND	GRASS_B
11.out	PERLND	WETLAND
13.out	IMPLND	RESIDENTIAL
14.out	IMPLND	COMMERCIAL
15.out	IMPLND	INDUSTRIAL
16.out	IMPLND	GOVT_INSTIT
17.out	IMPLND	TRANS_FREE

When linking to an existing watershed model, SUSTAIN associates land use time series to land use polygons in the GIS coverage. Because the GIS coverage does not differentiate pervious and impervious polygons, percent impervious assumptions from SEWRPC were used.

Table 3-8 shows the SEWRPC percent impervious assumptions by land use. Impervious area was assigned to the corresponding impervious land use boundary condition shown in Table 3-7. The most prevalent soil type within this study area was categorized as hydrologic soil group B; therefore, pervious areas from all urban land use categories were assigned the “Grass_B” land use time series. There was no forest or agricultural land uses (cropland or pasture) within the modeled drainage area.

Table 3-8. SEWRPC Percent Impervious Assumptions by Urban Land Use Category.

Land Use Group	Land Use Category	Percent Connected (DCIA)	Percent Supplemental	Percent Total Impervious
Residential	Estate	8	0	8
	Suburban	10	0	10
	Low	10	5	15
	Medium	15	8	23
	High	20	15	35
Commercial	All	60	0	60
Industrial	All	60	0	60
Transportation	Freeway	60	0	60
	Streets	50	0	50
	Parking	100	0	100
Government /institutional	All	25	0	25
Cemeteries	All	4	0	4
Recreational	All	4	0	4

DCIA = directly connected impervious area

3.5.2 Simulation Time Period

The optimization component of SUSTAIN requires numerous iterations of model simulation, making it impractical to use the model for the 64.5-year simulation period used by MACRO in Section 2. Instead, measured precipitation data at the General Mitchell International Airport (GMIA) were analyzed to identify a time period that reflects a range of weather variation that occurs in the watershed. Figure 3-12 is a graph of average annual precipitation volume for 1950 through 2009, with the first, middle, and last 10 years highlighted.

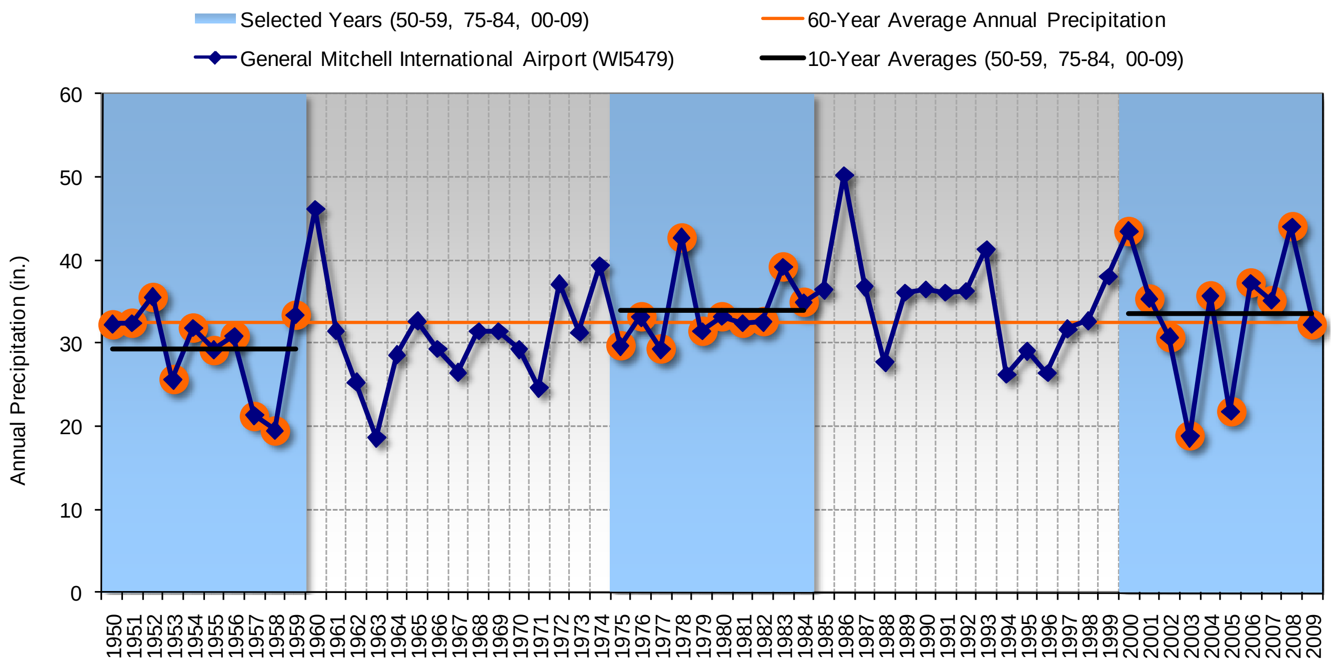
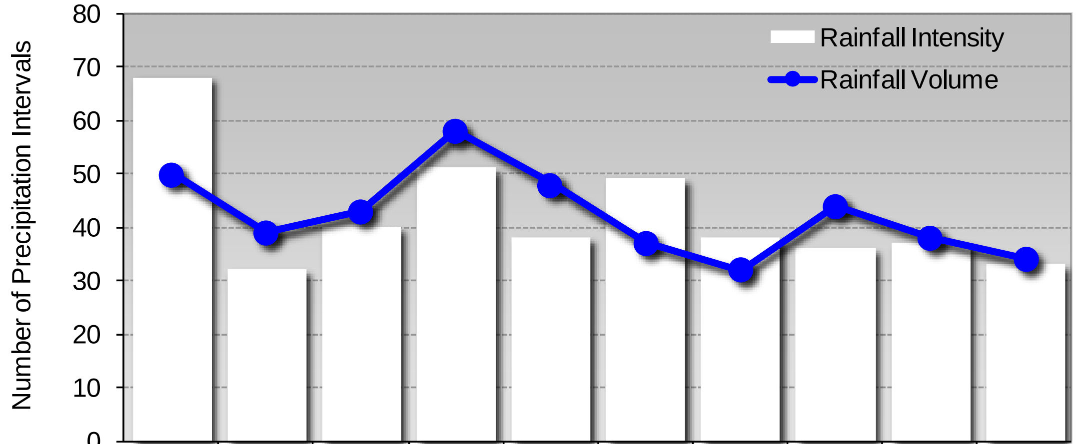


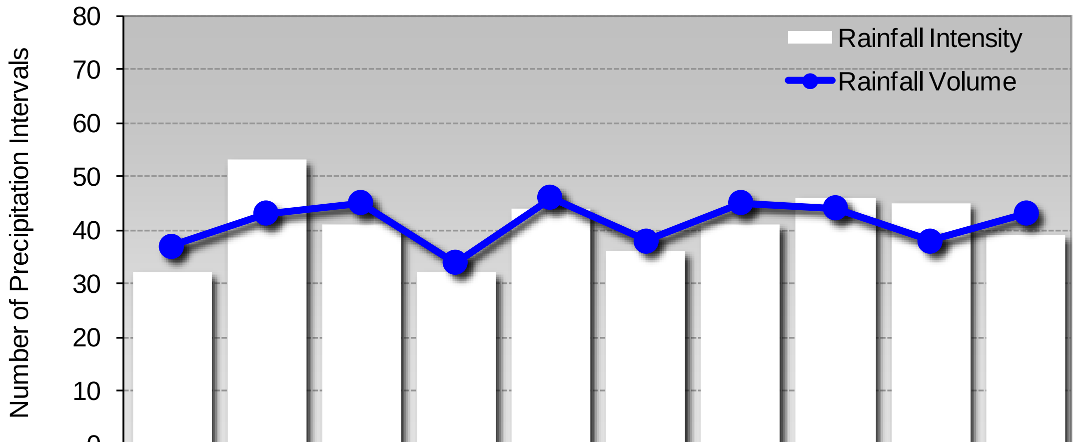
Figure 3-12. Annual Precipitation at General Mitchell International Airport for Years 1950–2009.

A simple linear trend line suggests a gradual increase in precipitation of approximately 0.1 inch per year over the 60 years. However, the average precipitation for the three selected (evenly spaced) 10-year periods varies around the linear trend line. The three 10-year periods were also evaluated for precipitation volume and intensity variation relative to the 60-year volume and intensity distribution. This first involved separating the observed hourly precipitation records into discrete storm intervals. Storm intervals were defined as continuous stretches of precipitation separated by at least 72 continuously dry hours. The storm interval classification averaged about 40 storm intervals per year. Figure 3-13, Figure 3-14, and Figure 3-15 show rainfall volume and intensity distributions for the three 10-year intervals 1950-1959, 1975-1984, and 2000-2009, respectively. In the figures, the volume and intensity percentile ranges are based on the entire record of storms occurring over the entire 60-year period.



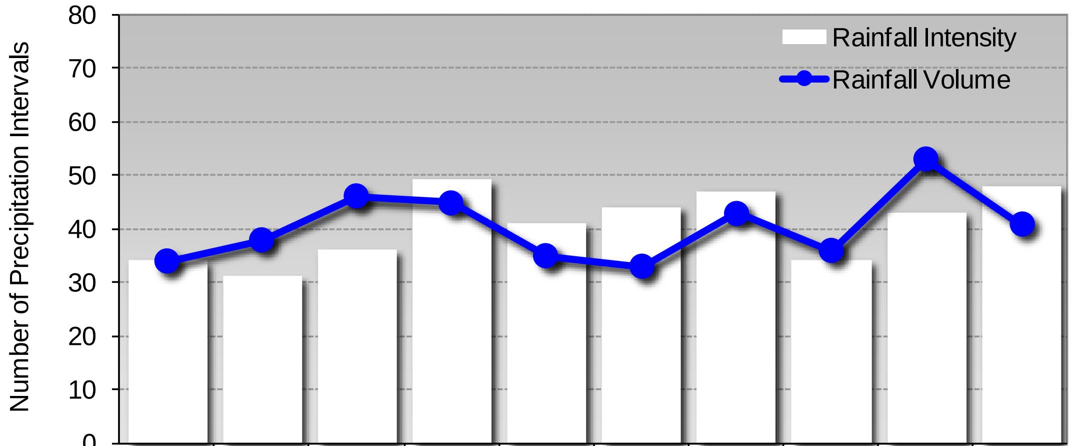
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Rainfall Intensity	68	32	40	51	38	49	38	36	37	33
Rainfall Volume	50	39	43	58	48	37	32	44	38	34

Figure 3-13. Rainfall Volume and Intensity Wet-interval Distribution for Years 1950–1959.



	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Rainfall Intensity	32	53	41	32	44	36	41	46	45	39
Rainfall Volume	37	43	45	34	46	38	45	44	38	43

Figure 3-14. Rainfall Volume and Intensity Wet-interval Distribution for Years 1975–1984.



	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Rainfall Intensity	34	31	36	49	41	44	47	34	43	48
Rainfall Volume	34	38	46	45	35	33	43	36	53	41

Figure 3-15. Rainfall Volume and Intensity Wet-interval Distribution for Years 2000–2009.

The chronological progression of these figures suggests that over the 60-year period, storms in the last decade evaluated (Figure 3-15) show a volume and intensity increase relative to the first decade (Figure 3-13). In fact, the first decade showed the strongest skew toward lower intensity and volume storm intervals. The middle decade (Figure 3-14), showed a relatively even volume and intensity distribution that was consistent with the 60-year volume and intensity distribution. Because storm volume and intensity are primary drivers for sizing green infrastructure practices, the decade with the most notable shift toward higher volume and intensity was selected to be the representative period for modeling. The 2000-2009 decade also represents the most recent recorded precipitation time period available at the time of this study.

3.5.3 Representation of Green Infrastructure Practices

Green infrastructure practices are simulated within SUSTAIN according to specific design specifications, with the performance modeled using a unit-process parameter-based approach. This contrasts with and has many advantages over most other modeling tools that simply assign a single percent effectiveness value to each type of practice.

The practices were simulated in aggregate, recognizing the scale and model resolution of the original watershed models. The aggregate approach is a computationally efficient and analytically robust way of evaluating relative practice selection and performance at a small subwatershed scale. An aggregate green infrastructure practice consists of a series of process-based optional components, including on-site interception, on-site treatment, routing attenuation, and regional storage/treatment. The aggregate component evaluates storage and infiltration characteristics from multiple practices simultaneously without explicit recognition of their spatial distribution and routing characteristics within the selected watershed. For this application, the aggregate practice included seven component practices—rain barrels, rain gardens, block bioretention, green alley, porous pavement, green roof, and regional bioretention. Figure 3-16 is a schematic diagram of aggregate components, drainage areas, and practice-to-practice routing networks.

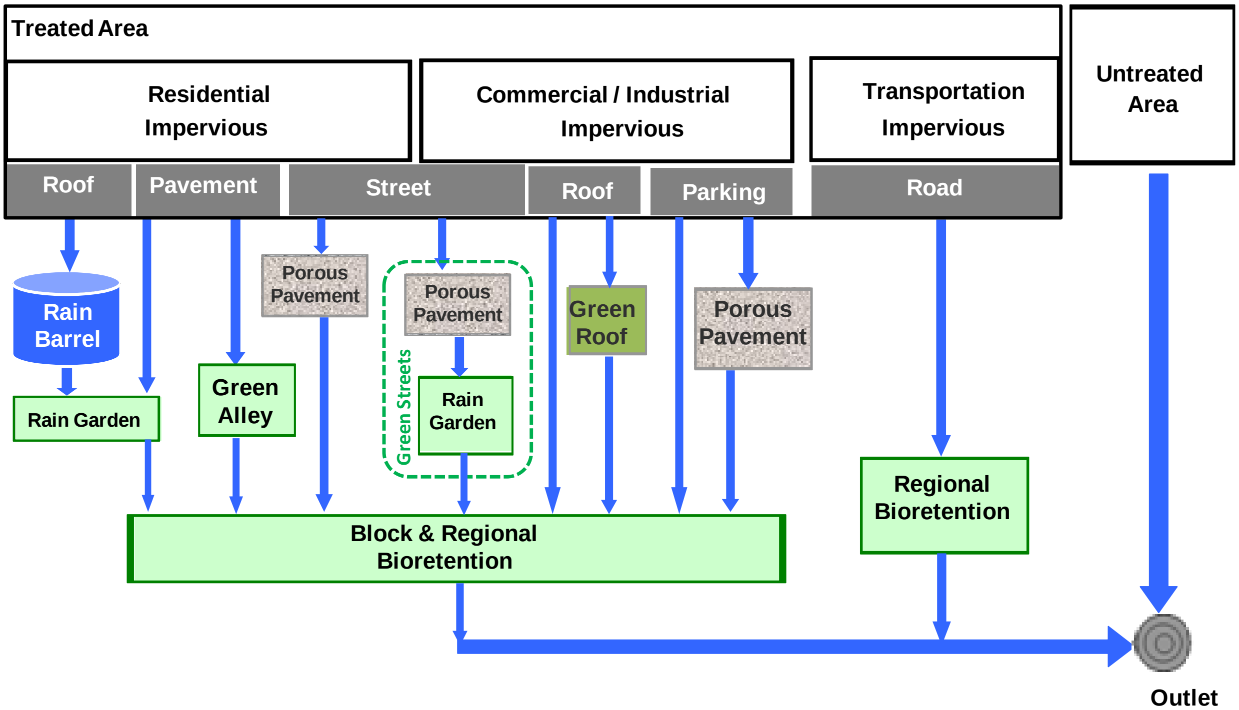


Figure 3-16. Aggregate Green Infrastructure Practice Schematic.

As shown in Figure 3-16, the rain barrel component collects runoff from rooftops (as part of the impervious surfaces) in residential areas. Outflow and bypass from the rain barrel is assumed to flow directly to residential rain gardens. Other residential impervious pavement areas can be treated by block bioretention or treated by a green alley first, and outflow from green alleys is routed to block bioretention. Highway runoff is assumed to flow to a regional bioretention site. Selected rooftops and pavement in commercial and industrial areas are available for conversion into green roofs and porous pavement sites, respectively. These two types of practices can treat up to the entire drainage area to which they are assigned. The neighborhood streets can be treated by road-side porous pavement, and larger connector streets can be treated by road-side porous pavement in series with rain gardens to make green streets. Outflow and bypass from these facilities are assumed to be captured by downstream block or regional bioretention sites. Some commercial and industrial areas that are not subject to green roof or porous pavement may also flow into block or regional bioretention facilities. Any other runoff from any type of land use that is not subject to treatment by any aggregate practice components is routed directly to the subbasin outlet.

To run the optimization analysis, the user must define decision variables that are used to explore the various possible practice configurations. The range and types of decision variables define the optimization search space. For this analysis, the decision variables include:

- Number of fixed-size rain barrel and rain garden units,
- Surface area of block and regional bioretention area,
- Surface area of porous pavement, green alleys, green roofs, road side porous pavement, and green streets.

Because the decision variable values can range anywhere between zero to a maximum number or size, it is possible for one component in the treatment train to never be selected if it is not cost-effective. During an optimization run, if the size value of zero for a practice is selected, that point will act as a transfer node in the network (i.e. inflow = outflow), and the associated cost that is a function of the number of practices or surface area will be set to zero. Table 3-6 previously summarized the maximum extent of each practice in each sewershed, defining the upper boundary of the optimization search space.

The physical configuration data, infiltration parameters, water quality parameters, and unit capital cost assumptions for each green infrastructure component are listed in Table 3-9. The main reference for the capital cost assumptions was the *Fresh Coast Green Solutions* publication (MMSD 2009) which provided general estimates for the proposed green infrastructure solutions based on past MMSD project experience and cost references including University of New Hampshire (2008), City of Portland (2009), and Federal Highway Administration (2009). Some of the cost estimates were adjusted to more specifically reflect the design assumptions in SUSTAIN. Rain gardens, as assumed in the model, were estimated to cost less than the *Fresh Coast Green Solutions* median estimate, and a similar local project was used as a reference to estimate the capital cost of $6 per square foot. Schueler et al. (2007) was used to estimate the capital cost of $15 per square foot for the remaining bioretention practices whose per unit costs are expected to be higher than rain gardens due to the inclusion of a gravel underdrain and the need for more extensive excavation and structural retrofits. Stormwater trees were also assumed for half of the bioretention cells based on the *Fresh Coast Green Solutions* cost. For porous pavement and green alleys, a $2 per square foot cost was added to the *Fresh Coast Green Solutions* medians to account for the inclusion of underdrains. For the remaining practices, the median of the *Fresh Coast Green Solutions* cost range was assumed without adjustment. Operation and maintenance were not included in these costs in order to be consistent with the *Fresh Coast Green Solutions* document.

Table 3-9. Green Infrastructure Practice Configuration Parameters.

Parameter	Rain Barrel	Bioretention				Porous Pavement	Green Alley	Green Roof
		Rain Garden	Street Rain Garden	Block	Regional			
Physical Configuration								
Unit size	60 gal	50 ft^2	N/A	N/A	N/A	N/A	N/A	N/A
Design drainage area (acre)	0.005	0.02	N/A	N/A	N/A	N/A	N/A	N/A
Substrate depth (ft)	N/A	1	2	2	2	2	2.5	0.3
Underdrain depth (ft)	N/A	N/A	1	1	1	1	1	0.1
Ponding depth (ft)	N/A	0.5	0.5	1.5	2	0.1	0.1	0.1
Infiltration (Source: Prince George's County 2001)								
Substrate layer porosity	N/A	0.45	0.45	0.45	0.45	0.5	0.5	0.5
Substrate layer field capacity	N/A	0.25	0.25	0.25	0.25	0.055	0.055	0.4
Substrate layer wilting point	N/A	0.1	0.1	0.1	0.1	0.05	0.05	0.1
Underdrain gravel layer porosity	N/A	N/A	0.5	0.5	0.5	0.5	0.5	0.5
Vegetative parameter, *A*	N/A	1	1	1	1	1	1	0.6
Background infiltration rate (in./hr), f_c	N/A	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Media final constant infiltration rate (in./hr), f_c	N/A	0.15	0.5	0.5	0.5	0.5	0.5	1
Water Quality (Source: calibrated values using University of Maryland monitoring data, Prince George's County 2003)								
Total suspended solids 1st order decay rate (1/day), *k*	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Total suspended solids filtration removal rate, P_{rem} (%)	N/A	85	85	85	85	70	70	70
Total nitrogen 1st order decay rate (1/day), *k*	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Total nitrogen filtration removal rate, P_{rem} (%)	n/a	35	35	35	35	20	20	20
Total phosphorus 1st order decay rate (1/day), *k*	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Total phosphorus filtration removal rate, P_{rem} (%)	n/a	n/a	65	65	65	50	50	50
Cost Data (Source: MMSD *Fresh Coast Solutions* publication)								
Unit Capital Cost	$118 ea.	$6 / ft^2	$15 / ft^2	$15 / ft^2	$15 / ft^2	$6 / ft^2	$11 / ft^2	$18 / ft^2

3.5.4 Optimization Formulation

The optimization objectives were to maximize annual volume reduction and to minimize implementation cost. As a result, the optimization outcome defines a set of solutions that show the maximum achievable volume reduction at each minimum-cost interval.

3.6 Model Results

Model results are presented below for (1) the cost-effectiveness curve, (2) performance summaries by storm size for selected solutions along the cost effectiveness curve, and (3) performance summaries for two selected storms. This section concludes with a summary of observations from this analysis.

3.6.1 Cost-Effectiveness Curve

Figure 3-17 shows the average annual runoff volume reduction cost-effectiveness curve within the study area, as defined by the aggregate decision variables. In this figure, the small points represent all solutions that were evaluated during optimization, while the larger points along the left-and-upper-most perimeter represent the least cost options at each volume reduction interval. The maximum achievable volume control through the use of all potential green infrastructure practices within the study area is around 85 percent; however, there is clearly a point above which the marginal costs of additional controls increases dramatically. To further investigate this, four solutions at different intervals along the curve (the larger, highlighted points on Figure 3-17, and shown in Table 3-10) were selected for detailed performance evaluation.

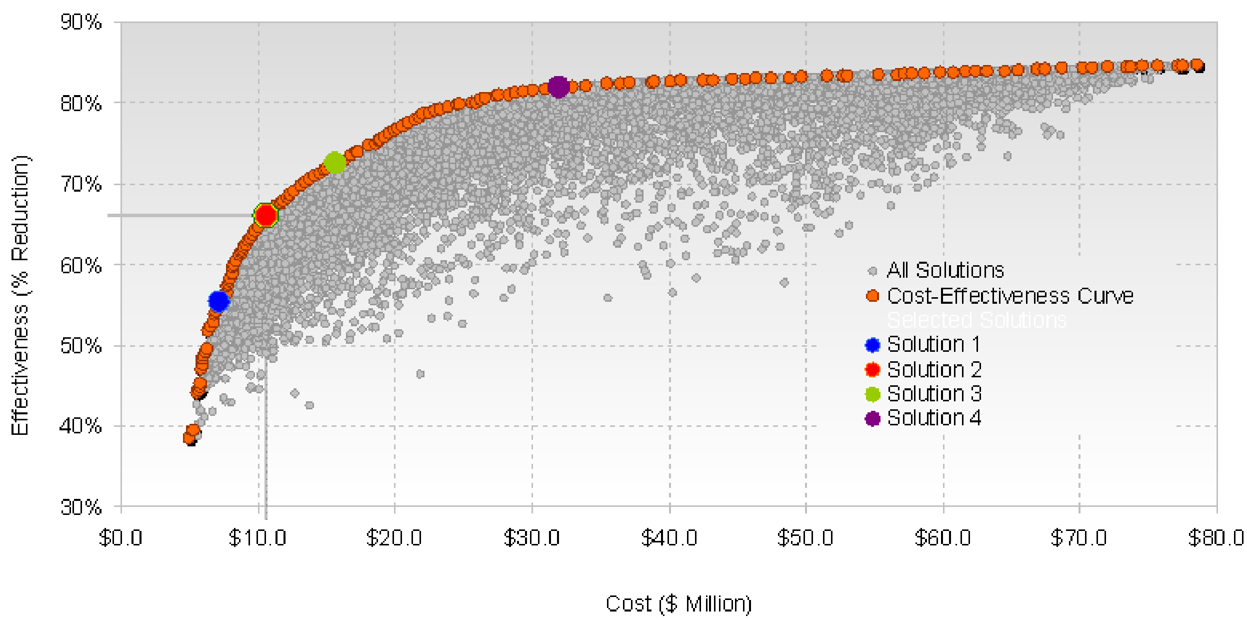


Figure 3-17. Maximum Runoff Volume Control Cost-effectiveness Curve.

Table 3-10. Selected Solutions around the Knee of the Cost-effectiveness Curve.

Selected Solution	Cost ($ Million)	Annual Runoff Volume Reduction (%)
1	7.2	55.4%
2	10.6	66.0%
3	15.7	72.6%
4	32.0	81.9%

Figure 3-18 through Figure 3-21 correspond to each of the four points highlighted in Figure 3-17 and listed in Table 3-10. In each of these figures, the top panel shows the highlighted point on the cost-effectiveness curve, while the bottom panel shows the cost distribution at each volume reduction interval. The pie chart shows the cost distribution among individual green infrastructure practices for the selected solutions marked along the curve.

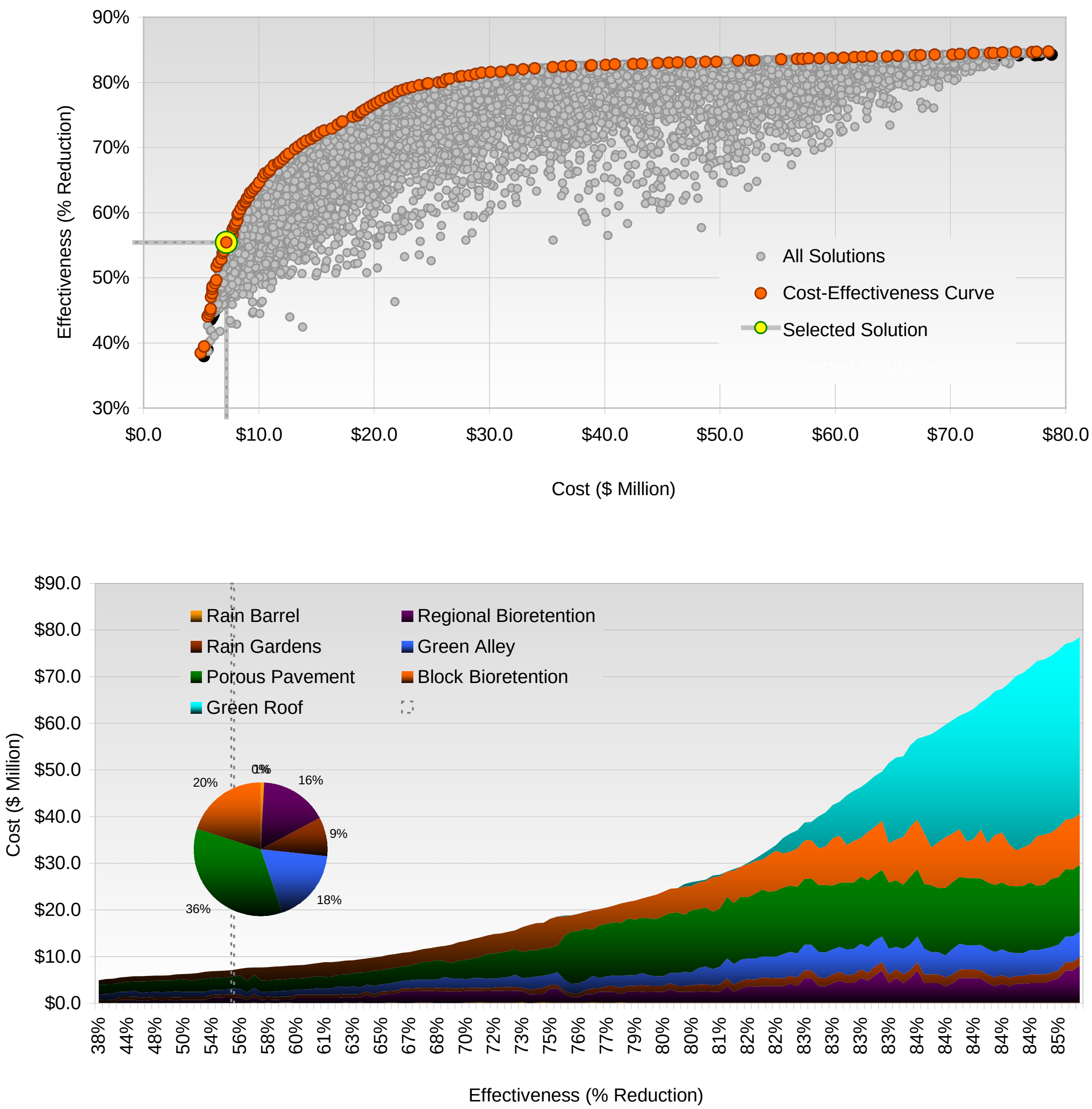


Figure 3-18. Cost-effectiveness Curve and Selected Solution 1.

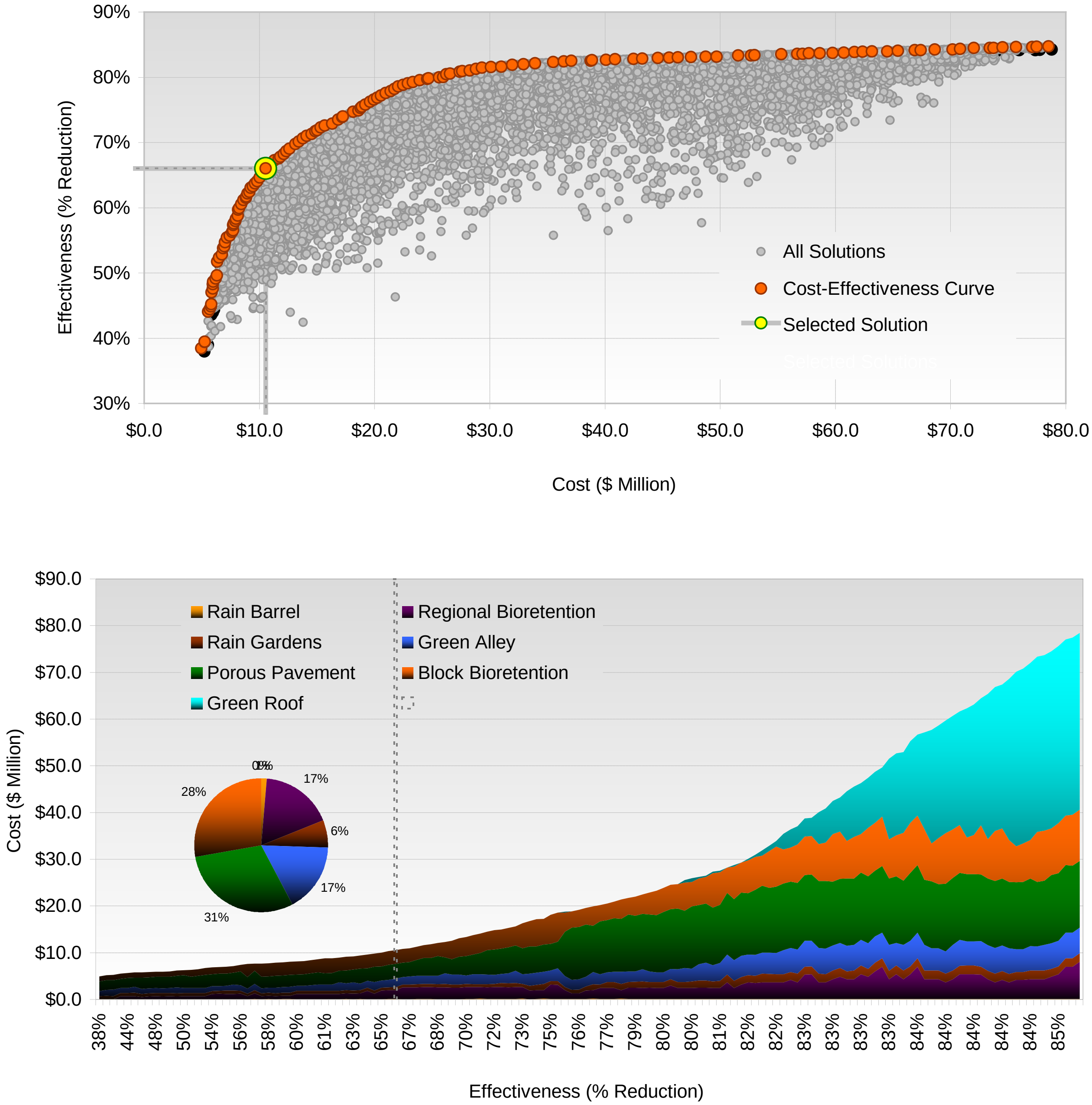


Figure 3-19. Cost-effectiveness Curve and Selected Solution 2.

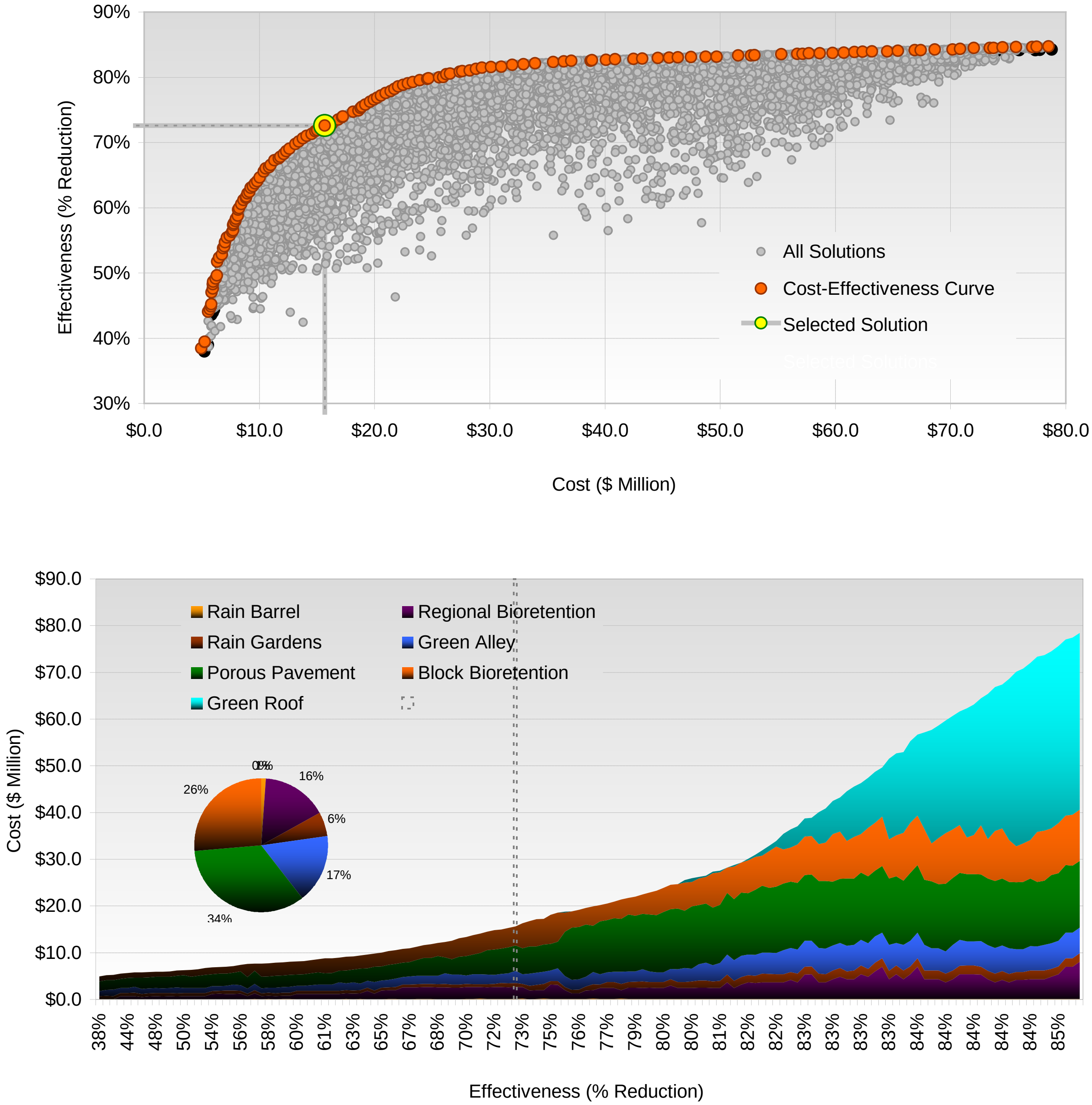


Figure 3-20. Cost-effectiveness Curve and Selected Solution 3.

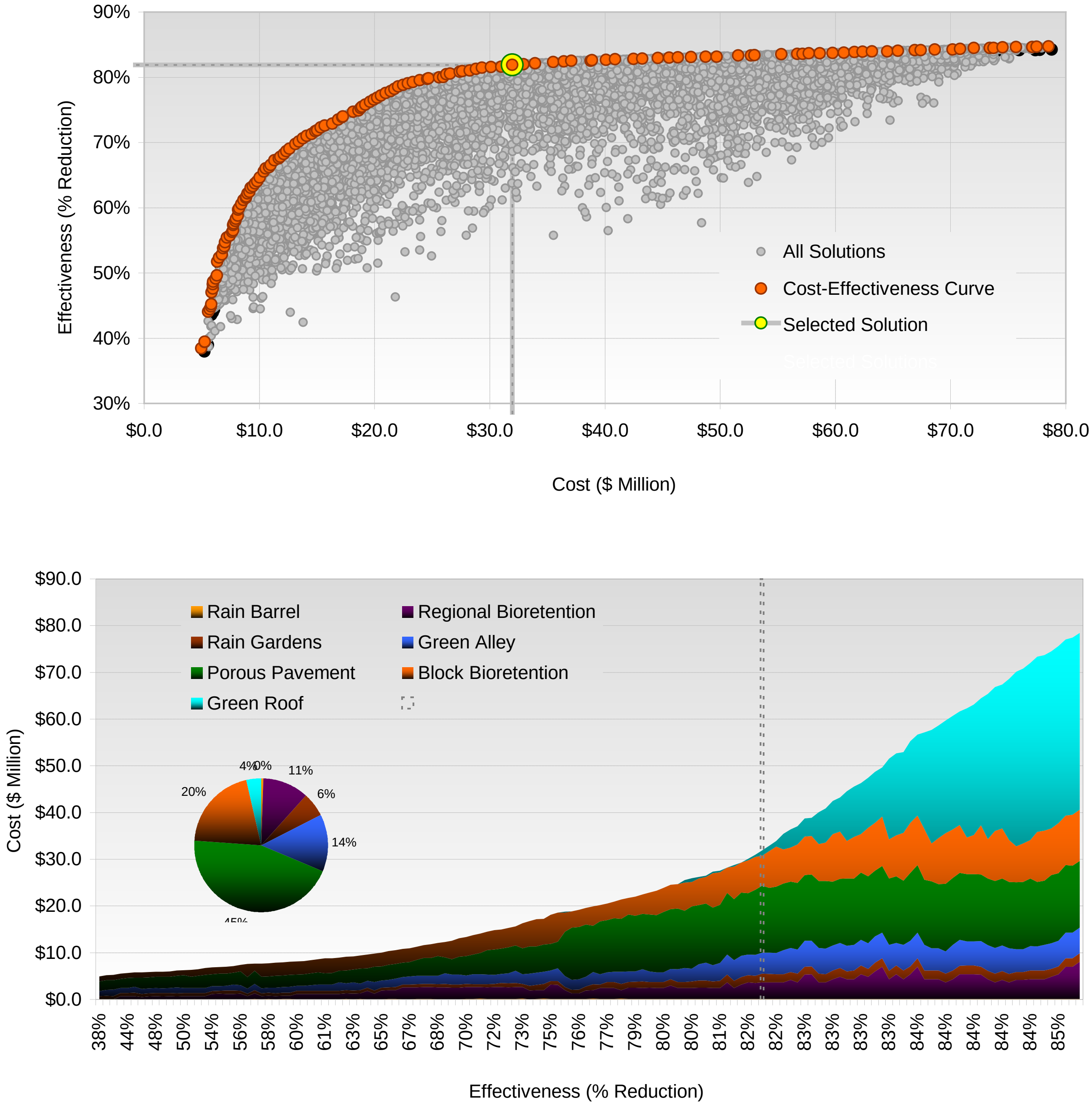
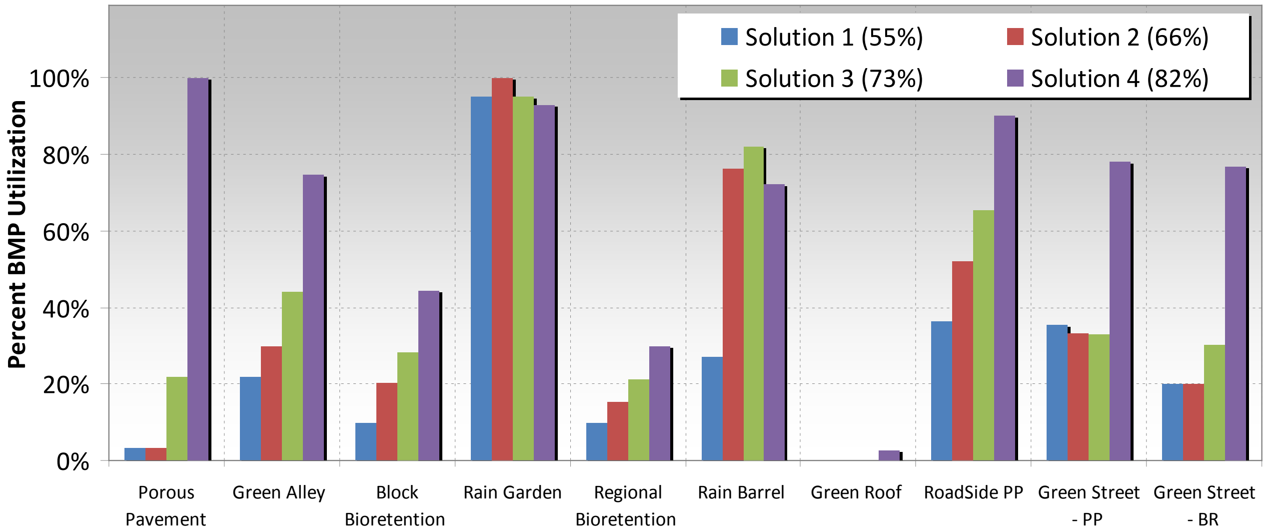


Figure 3-21. Cost-effectiveness Curve and Selected Solution 4.

The utilization percentage of each practice for the four solutions is plotted in Figure 3-22. Percent utilization for each solution is defined as the ratio of how much of the available opportunity was used divided by the total available opportunity. Figure 3-22 illustrates how utilization changes for each practice as cost and percent volume control increases while moving up the curve. The extent to which each practice is used for the four selected solutions is presented in Table 3-11 to Table 3-14. The total area for each practice and the percentage of the total maximum extent (from Table 3-6) is also presented.



Percentages shown in parenthesis next to each solution in the legend above indicate modeled percent runoff volume reduction.

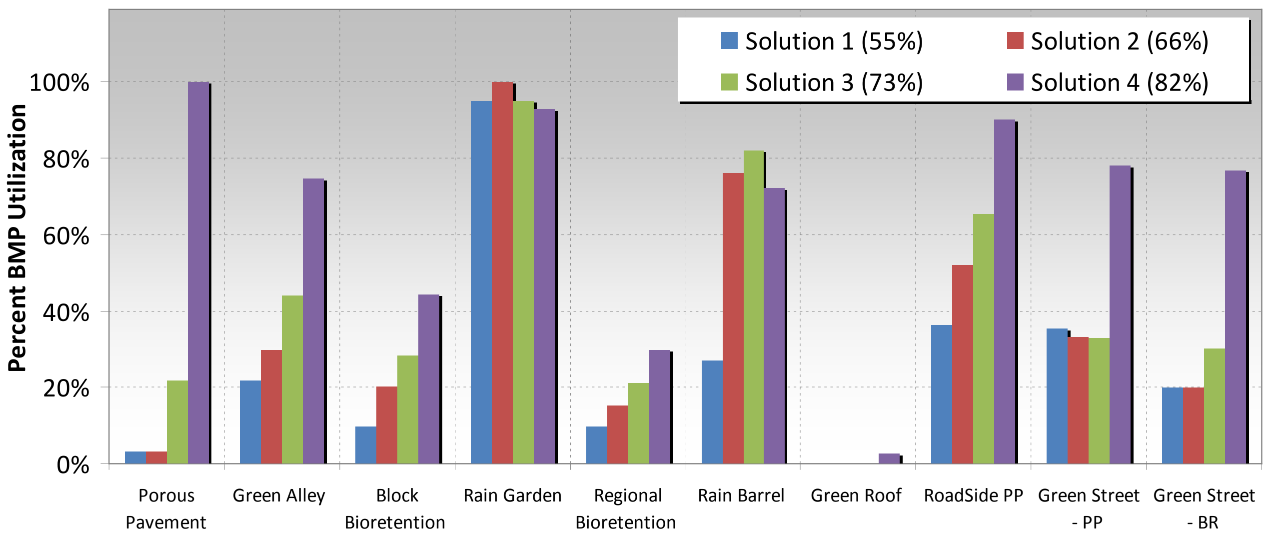


Figure 3-22. Percent Utilization of Various Green Infrastructure Practices.

Table 3-11. Solution 1 Green Infrastructure Extent by Sewershed.

Practices		CS5134#2	CS5134#1-W	CS5135A3	CS5134#1-E
Porous pavement (acre)		0.8	-	0.3	-
Green alley (acre)		0.6	1.3	0.8	-
Block bioretention (acre)		0.2	0.6	0.9	0.5
Rain garden (unit)		250	400	160	-
Regional bioretention (acre)		-	0.8	-	1.0
Rain barrel (unit)		100	80	280	-
Green roof (acre)		-	-	-	-
Road side porous pavement (acre)		1.0	1.8	1.2	1.9
Green street	Road side porous pavement (acre)	0.6	1.1	0.6	0.4
	Rain garden (acre)	0.2	0.1	0.2	0.1

Table 3-12. Solution 2 Green Infrastructure Extent by Sewershed.

Practices		CS5134#2	CS5134#1-W	CS5135A3	CS5134#1-E
Porous pavement (acre)		0.8	-	0.3	-
Green alley (acre)		1.0	2.0	0.8	-
Block bioretention (acre)		0.4	0.6	0.9	2.6
Rain garden (unit)		250	400	200	-
Regional bioretention (acre)		-	0.8	-	2.0
Rain barrel (unit)		300	720	280	-
Green roof (acre)		-	-	-	-
Road side porous pavement (acre)		2.4	3.0	1.2	1.9
Green street	Road side porous pavement (acre)	0.5	1.1	0.6	0.4
	Rain garden (acre)	0.2	0.1	0.2	0.1

Table 3-13. Solution 3 Green Infrastructure Extent by Sewershed.

Practices		CS5134#2	CS5134#1-W	CS5135A3	CS5134#1-E
Porous pavement (acre)		1.7	3.0	0.3	2.7
Green alley (acre)		1.3	2.6	1.6	-
Block bioretention (acre)		0.4	0.6	2.7	2.6
Rain garden (unit)		250	400	160	-
Regional bioretention (acre)		-	0.8	-	3.0
Rain barrel (unit)		400	800	200	-
Green roof (acre)		-	-	-	-
Road side porous pavement (acre)		2.4	4.7	1.2	2.2
Green street	Road side porous pavement (acre)	0.6	1.1	0.4	0.4
	Rain garden (acre)	0.2	0.3	0.2	0.3

Table 3-14. Solution 4 Green Infrastructure Extent by Sewershed.

Practices		CS5134#2	CS5134#1-W	CS5135A3	CS5134#1-E
Porous pavement (acre)		1.7	3.3	3.3	26.9
Green alley (acre)		2.6	5.9	0.8	-
Block bioretention (acre)		0.4	1.2	3.6	4.7
Rain garden (unit)		250	400	140	-
Regional bioretention (acre)		-	2.4	-	3.0
Rain barrel (unit)		150	800	280	-
Green roof (acre)		0.7	0.8	-	-
Road side porous pavement (acre)		3.4	5.3	2.5	3.4
Green street	Road side porous pavement (acre)	1.3	2.6	0.8	1.2
	Rain garden (acre)	0.6	1.0	0.3	0.6

3.6.2 Performance Summary by Storm Size

Each point on the cost-effectiveness curve represents an average performance over all storm events that occur during the model simulation time period. Evaluating the performance by individual storms provides insight into the size of storms that are completely contained versus those that reflect diminished performance due to bypass or overflow.

Figure 3-23 to Figure 3-26 plot the flow volume reduction effectiveness by storm size for the four selected solutions, respectively. A hypothetical pre-developed condition was also simulated and compared against the existing condition and the modeled condition for reference purposes. The pre-developed condition for this simulation was modeled as bare land without impervious cover, as represented by the “Grass_B” model time series. The ratio of pre-developed runoff volume to existing condition without green infrastructure is plotted as the gray dashed series in Figure 3-23 to Figure 3-26.

In each of these graphs, the X-axis shows storm sizes for different storm events, while the primary Y-axis shows percent volume reduction. The circle and dashed series are read off of the primary Y-axis. The secondary Y-Axis, which corresponds to the bar graphs, shows relative runoff volume contribution for each event. The storm sizes are sorted according to the relative volume contribution of that event over the simulation period. Green infrastructure performance measured by percent volume reduction is a function of rainfall volume, intensity, duration, and antecedent condition. The next section will take a closer look at individual storm performance. It is further evident from this analysis that performance also varies as a function of runoff volume captured.

These figures all show a general trend of diminishing performance with increasing storm size. In general, the higher the level of treatment, the more performance begins to approach or exceed the pre-developed condition. An interesting observation is that the solutions with higher levels of treatment show less performance variation among different storm sizes, also the storm size where the performance declines increases with higher treatment level. For example, for solution 1, at around a 1 inch storm, the percent volume reduction starts to drop, comparing with around a 1.4 inch storm for solution 2. This reflects the fact that, at higher levels of treatment, larger size storms can be treated without compromising effectiveness.

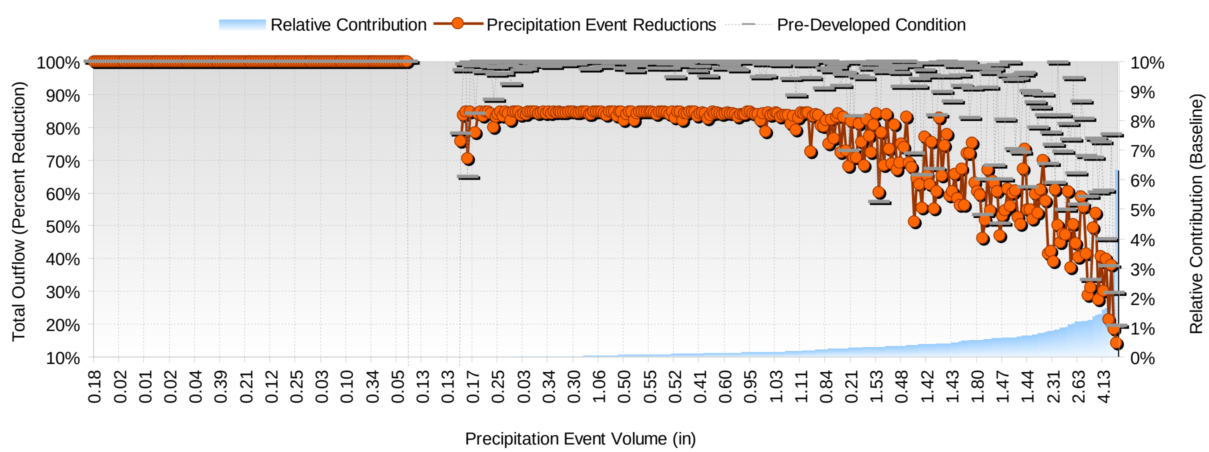


Figure 3-23. Solution 1 Flow Volume Reduction Effectiveness by Storm Events.

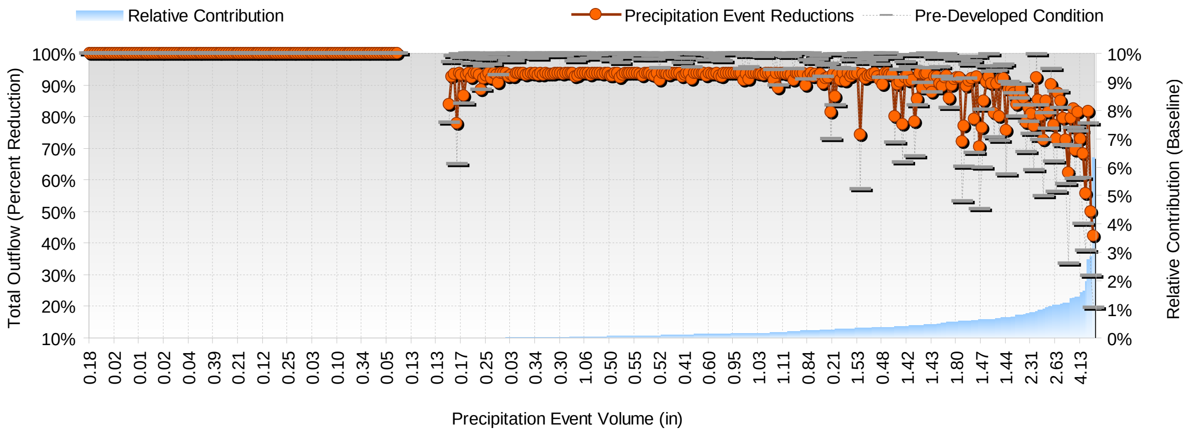


Figure 3-24. Solution 2 Flow Volume Reduction Effectiveness by Storm Events.

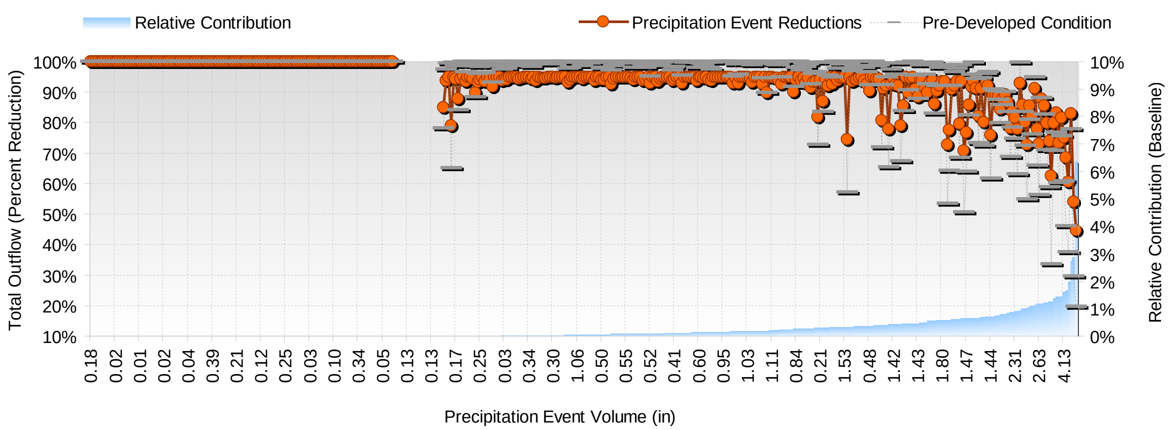


Figure 3-25. Solution 3 Flow Volume Reduction Effectiveness by Storm Events.

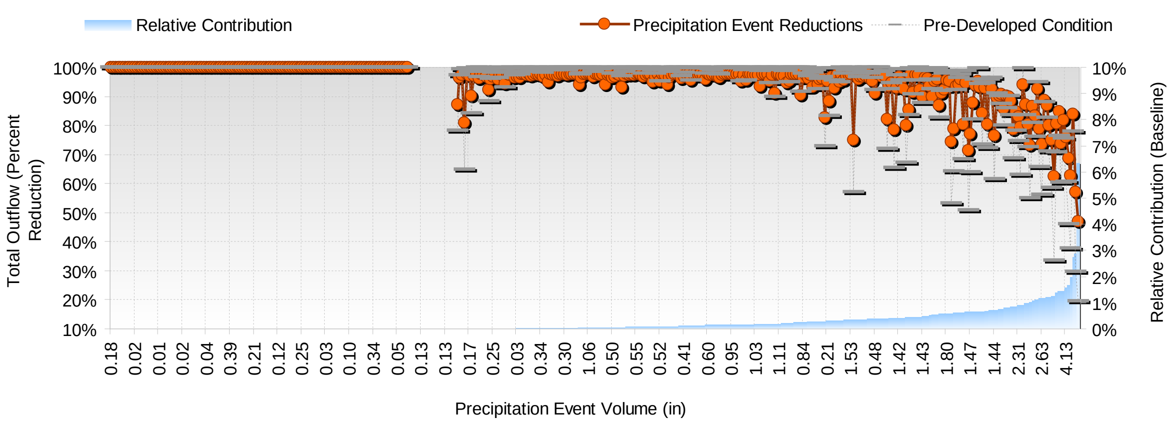


Figure 3-26. Solution 4 Flow Volume Reduction Effectiveness by Storm Events.

3.6.3 Performance Summary for Selected Events

The two representative events described in Table 2-3 were selected to further examine the performance of green infrastructure practices on the hydrograph. The June 2001 event (June 11-16, 2001) is a typical rainfall event with a magnitude that is likely in any year. The June 2001 event had 1.75 inches in 12 hours with the peak hourly intensity of 0.5 inch. The July 2000 event (July 1-7, 2000) is a large event with approximately 2 percent probability of occurrence (50-year event) in any year. It had 4.4 inches of precipitation within 6 hours with the peak hourly intensity of 1.8 inches.

The June 2001 event storm hyetograph, post-developed condition, green infrastructure scenario, and pre-developed condition hydrographs for solution 2 are plotted in Figure 3-27. Table 3-15 compares the volume reduction and peak attenuation effectiveness of the four selected solutions for the June 2001 even. It is evident that the solution with a higher level of treatment (solution 4) yields a higher peak attenuation and volume reduction.

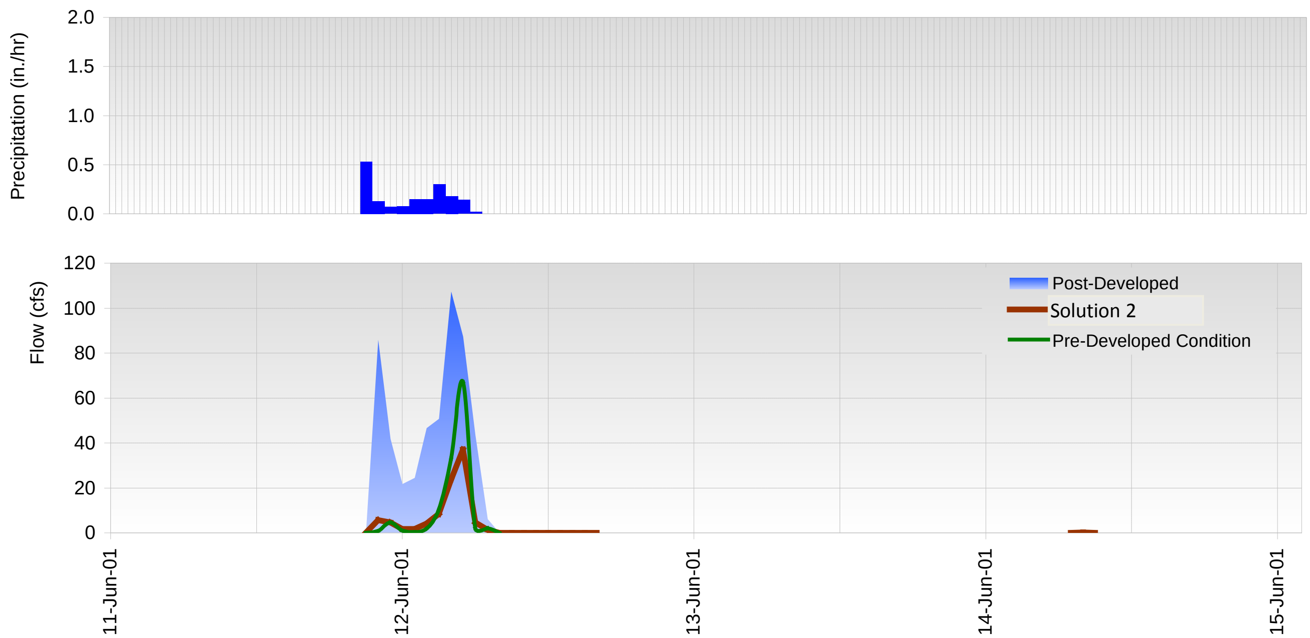


Figure 3-27. Solution 2 Hydrograph for the June 2001 Storm Event.

Table 3-15. Runoff Volume Reduction and Peak Attenuation Comparison of the Four Selected Solutions (June 2001 Storm Event).

Solutions	Post-Development Condition	Solution 1	Solution 2	Solution 3	Solution 4
Runoff volume (ac-ft)	42.7	15.8	9.7	9.0	7.7
Peak flow (cfs)	107.5	55.6	40.2	39.3	37.1
Volume reduction (%)	-	63.0%	77.2%	78.9%	82.0%
Peak flow reduction (%)	-	48.3%	62.6%	63.5%	65.5%

Figure 3-28 through Figure 3-31 are plots of the storm hyetograph, post-developed condition, green infrastructure scenario, and pre-developed condition hydrographs for solutions 1, 2, 3, and 4, respectively, for the 50-year (July 2000) storm event. Because the rainfall is a double-peak event and the first peak likely saturated the ground, these graphs show that even the pre-developed condition produces almost as much runoff as the developed watershed with impervious area for the second peak. Nevertheless, the trend observed between Figure 3-28 (solution 1) and Figure 3-31 (solution 4) suggests that the additional storage and attenuation benefit provided by the green infrastructure was able to provide volume reduction as well as peak attenuation. Table 3-16 summarizes the volume reduction and peak attenuation effectiveness of the four selected solutions for the July 2000 event.

Table 3-16. Runoff Volume Reduction and Peak Attenuation Comparison of the Four Selected Solutions (July 2000 Storm Event)

	Post-Development Condition	Solution 1	Solution 2	Solution 3	Solution 4
Runoff volume (ac-ft)	168.4	137.1	122.3	104.4	72.2
Peak flow (cfs)	1,054.5	912.9	851.9	707.1	553.7
Volume reduction (%)	-	18.6%	27.4%	38.0%	57.1%
Peak flow reduction (%)	-	13.4%	19.2%	32.9%	47.5%

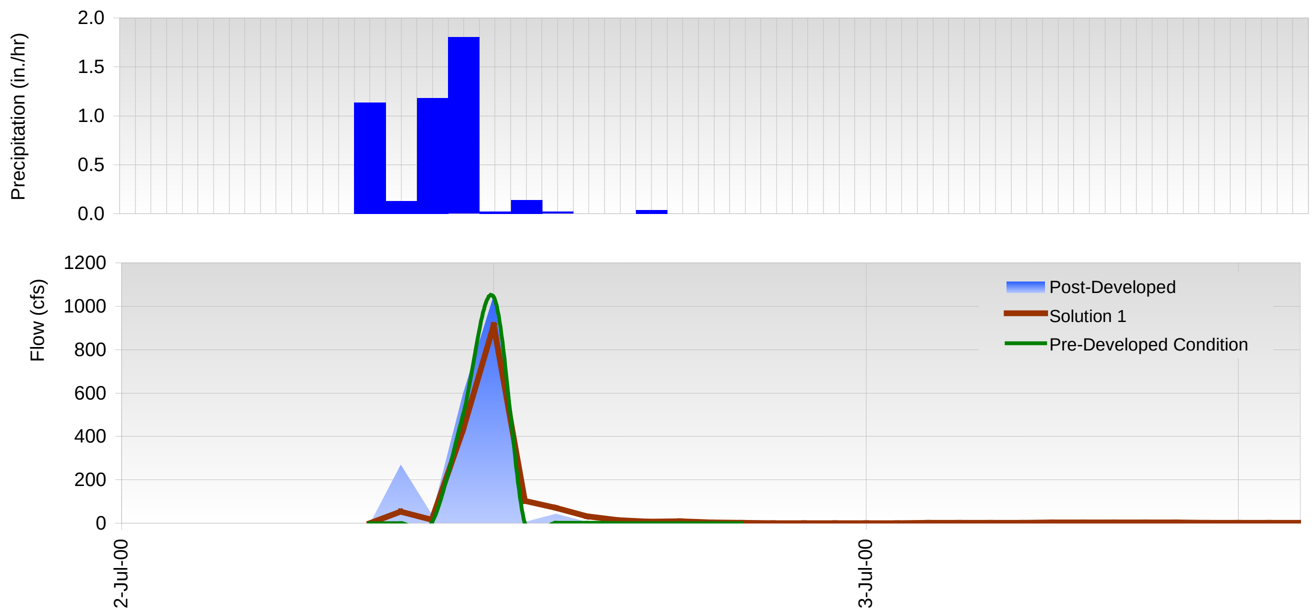


Figure 3-28. Solution 1 Hydrograph for the July 2000 Storm Event.

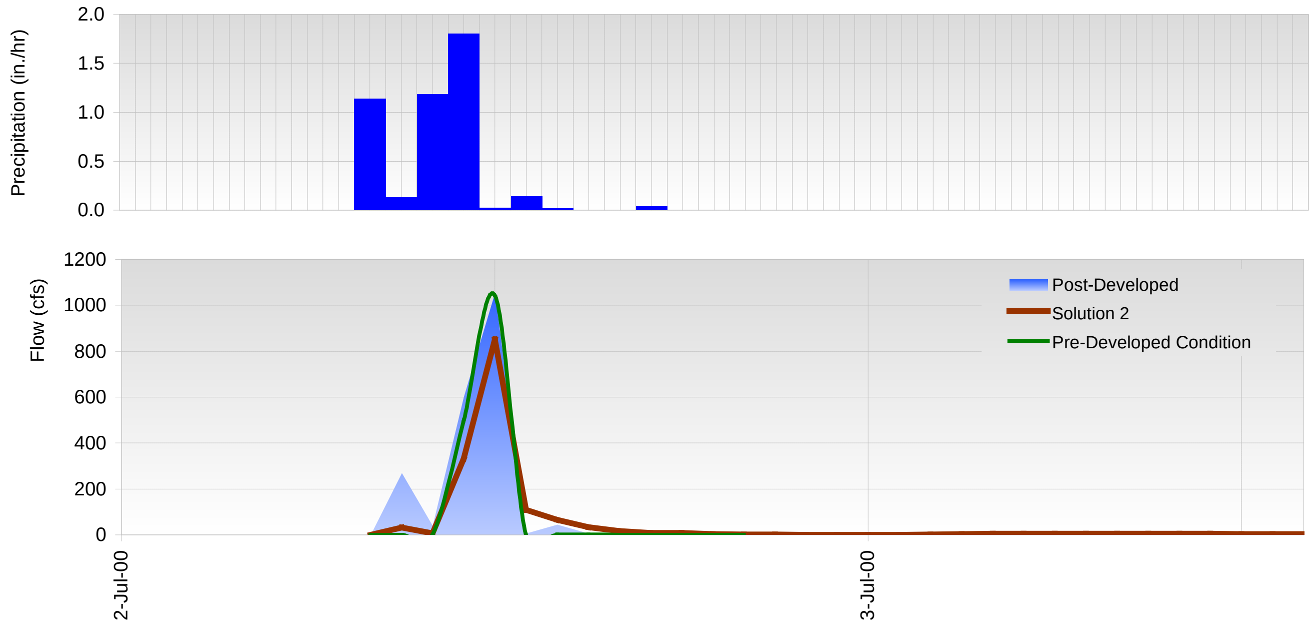


Figure 3-29. Solution 2 Hydrograph for the July 2000 Storm Event.

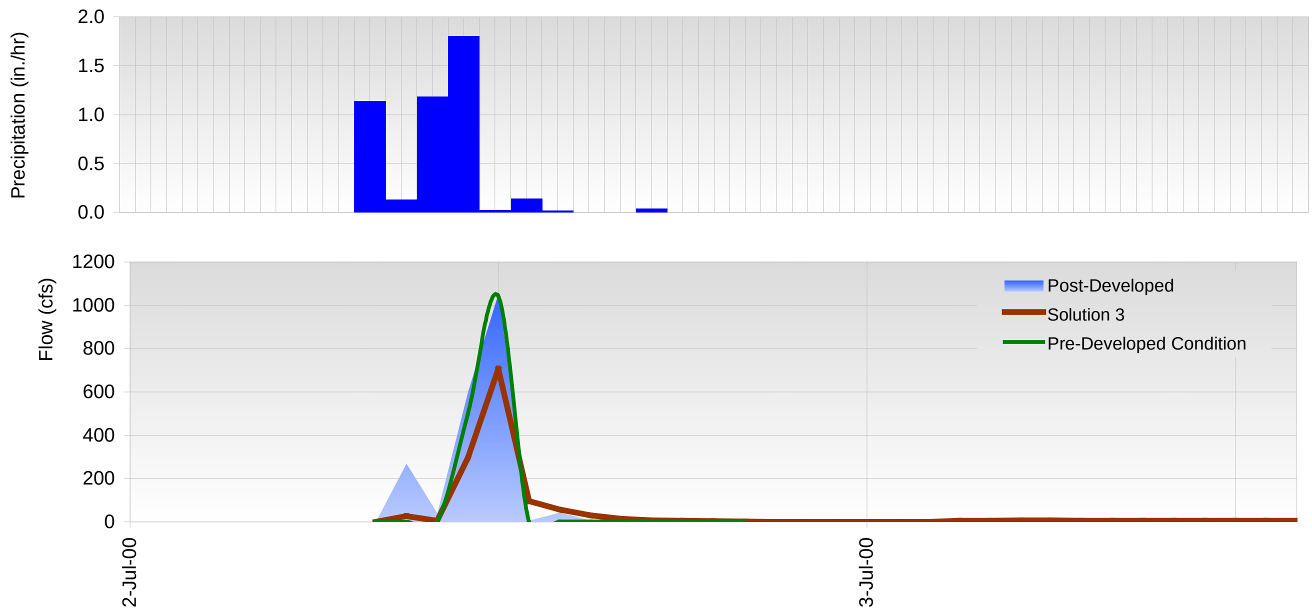


Figure 3-30. Solution 3 Hydrograph for the July 2000 Storm Event.

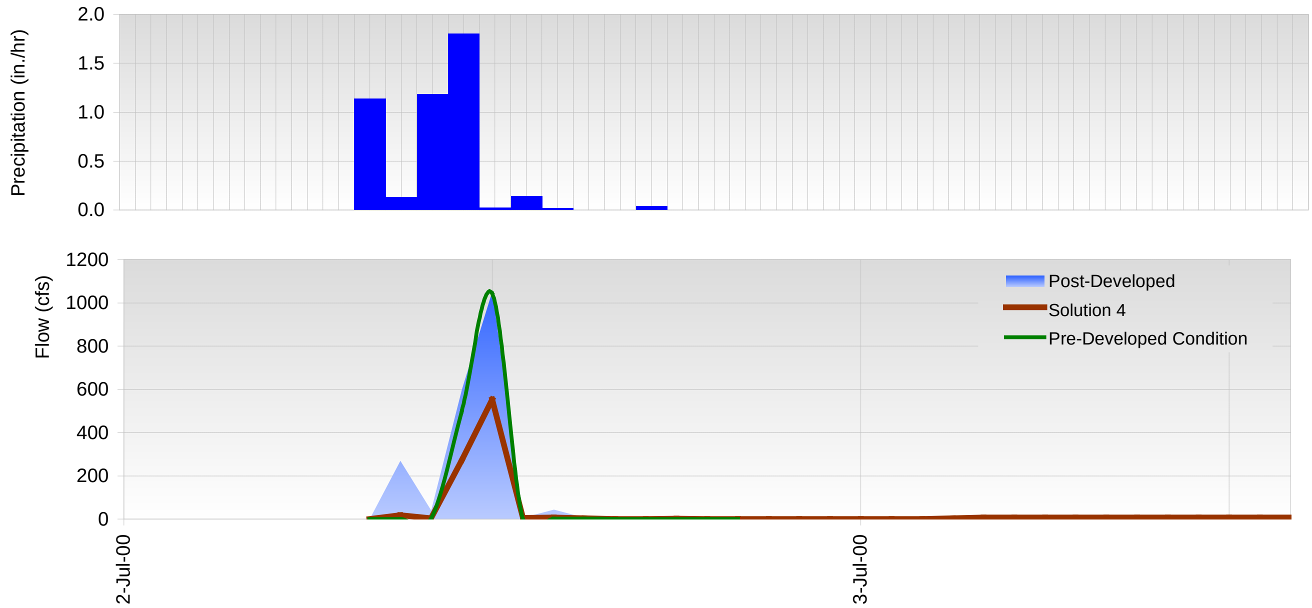


Figure 3-31. Solution 4 Hydrograph for the July 2000 Storm Event.

3.6.4 Performance Summary for Water Quality Parameters

The pollutant removal percentages for total suspended solids (TSS), total nitrogen (TN), and total phosphorus (TP) are listed for the four selected solutions in Table 3-17. Figure 3-32 is a graph highlighting pollutant removal rates by solution. Because water quality performance is partially a function of hydrologic modification, annualized flow volume and peak reduction are also plotted on this graph for relative comparison with the water quality parameters. It shows a trend of increasing average percent reduction moving up the cost effectiveness curve; it also shows a decline in the rate at which most pollutant removal increases with increasing treatment level. However, peak flows do not follow this same trend; the rate of peak flow reduction increases with higher treatment level.

Table 3-17. Pollutant Reductions of the Four Selected Solutions.

Solution ID	Flow Volume	Peak Flow	TSS	TN	TP	Cost ($ millions)
Solution 1	55.4%	13.4%	33.5%	25.1%	29.1%	7.2
Solution 2	66.0%	19.2%	39.5%	27.6%	31.3%	10.6
Solution 3	72.6%	32.9%	41.4%	28.9%	32.3%	15.7
Solution 4	81.9%	47.5%	44.6%	30.7%	34.1%	32.0

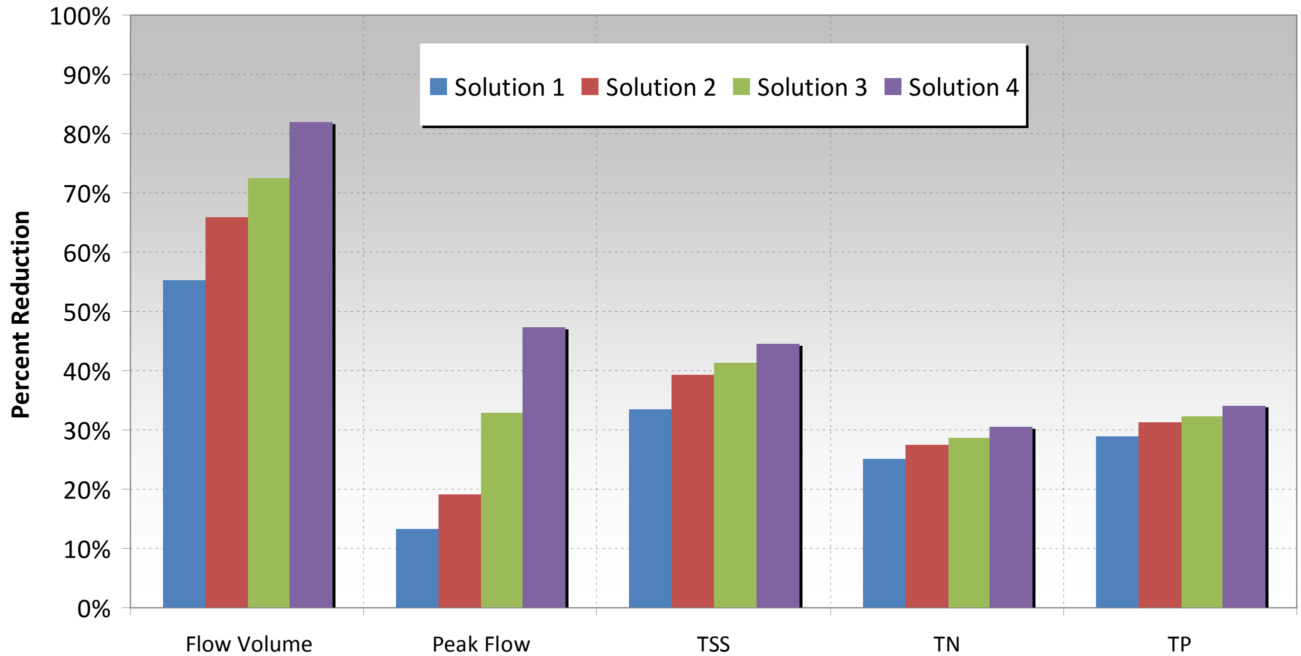


Figure 3-32. Flow Volume, Peak Flow, and Pollutant Loading Reductions of the Four Selected Solutions.

3.6.5 Summary of Observations

Below is a summary of observations from this analysis:

- Figure 3-22 shows that rain gardens were the most utilized practice for each of the four selected solutions. (Recall that percent utilization is defined as the ratio of how much of the available opportunity was used in each solution divided by the total available opportunity.) This indicates that rain gardens are the most cost-effective green infrastructure practice (see Section 5 for an estimated present worth cost comparison). The percent utilization of rain gardens reached 100 percent in solution 2; however, it dropped slightly in solutions 3 and 4, because additional treatment capacity was provided by block and regional bioretention.
- Figure 3-22 shows the percent utilization of rain barrels increases at higher treatment levels, however there is a slight decrease in solution 4 because of the decreased use of rain gardens. Rain barrels and rain gardens were modeled as being used in series; therefore, rain barrels act as supplemental storage to extend the infiltration potential of rain gardens.
- Figure 3-22 illustrates that the utilization of porous pavement increased dramatically to 22 percent for Solution 3 and then increased to 100 percent for Solution 4. This indicates that porous pavement is not a cost-effective practice for lower levels of volume reduction, but is needed to achieve volume reductions above 66 percent.
- The percent utilization of block bioretention, green alleys, regional bioretention, road side porous pavement, and green streets are always less than 100 percent (Figure 3-22). This indicates that the maximum potential extent of these practices exceeds the corresponding drainage area. Increasing the use of these practices above this maximum value therefore only increases cost without providing any additional benefit.
- The cost distribution plots (Figure 3-19) reveal that the green roof is the least cost-effective practice for achieving runoff volume reduction. These plots also show the total annual volume reduction added by maximizing the use of green roofs is roughly 3 percent, at a total cost of around $55 million. However, green roofs provide a number of other benefits, such as reduced energy demands, as documented in Section 5.

- Evapotranspiration (including that which occurs from the water stored in the growing media) is the only mechanism that contributes to volume reduction in green roofs, although green roofs do provide other benefits such as reduced energy costs. Infiltration to the relatively well-draining background soil occurs in many of the other practices, which contributes to making them more cost-effective for volume reduction.
- Optimization results are highly dependent on the model assumptions and the optimization problem formulation of defined objectives and constraints. The objective defined in this study is reducing the annual average flow volume only. Other conceivable factors such as peak flow attenuation, pollutant reduction, aesthetic appeal, and energy reduction benefit, are not considered.

3.7 Implications for the Entire CSSA

The MACRO simulation results presented in Section 2 provide estimates of CSO volume reduction for the entire service area based on reductions of impervious surface. At this time, MACRO is the only model available to estimate the effects of green infrastructure on CSO volumes. Although conversion to pervious land is not an exact comparison to treatment with green infrastructure, the MACRO results provide a means for estimating the approximate range of volume reduction that could be achieved with green infrastructure. The following results are from the long-term simulation which indicates the overall impact of green infrastructure averaged over many decades, but they do not indicate the level of CSO reduction that should be expected in each and every year.

An initial comparison of the runoff reduced between the MACRO (entire CSSA) and SUSTAIN (pilot area only) model results provides a conservative assumption of the green infrastructure volume reduction. Solution 2 would achieve about half of the annual runoff volume reduction achieved by the 400-acre (four percent) pervious conversion MACRO run in the pilot area alone. If the MACRO results are scaled by half, the results are 27 MG of CSO volume reduction per year, and 87 MG of reduced pumping volume per year. The true estimate of reductions for green infrastructure for solution 2 is likely somewhere between these two estimates. The midpoint of the range represents a 41 MG reduction of CSO volume per year, 129 MG of reduced pumping volume per year, and a 0.15 reduction in the frequency of CSO events per year due to the extremely high level of green infrastructure implementation in the pilot area alone. For the purposes of the Triple Bottom Line Analysis in Section 5, the midpoint values were used to represent the approximate tunnel pumping and CSO reduction benefits of solution 2.

Solution 2 from the SUSTAIN modeling was used to inform a fourth run of the MACRO model. The amount of green infrastructure in solution 2 represents a conversion of nearly 225 acres of impervious surface drainage area to pervious surface drainage area out of a total impervious area of 297 acres. This represents the conversion of 76 percent of the existing impervious area to pervious land use.

The MACRO model was run with 76 percent (approximately 8,125 acres) of the total impervious area of the CSSA (10,725 acres) converted to pervious land use. It should be noted that this reflects an extremely high level of adoption of green infrastructure and is intended primarily to provide an upper bound on what may be possible.

Figure 3-33 shows the reduction in simulated CSO volume and CSO frequency for various degrees of conversion of impervious area to pervious land use. The curve ranges from the baseline case to complete conversion of all impervious area to pervious land use. With 76 percent of the impervious area converted, the simulated average annual CSO volume (155 MG) is approximately one fifth of the baseline value (771 MG) and the simulated average CSO frequency is less than one event per year. Note that even with 100 percent of the impervious area converted to pervious land use, the simulation shows CSOs would still occur.

There is some uncertainty as to the actual amount of imperviousness in the CSSA, with the value used in MACRO higher than the value used in the SUSTAIN analysis. Additional, more detailed modeling within the CSSA will be needed to obtain a better understanding of the potential for green infrastructure throughout the entire CSSA.

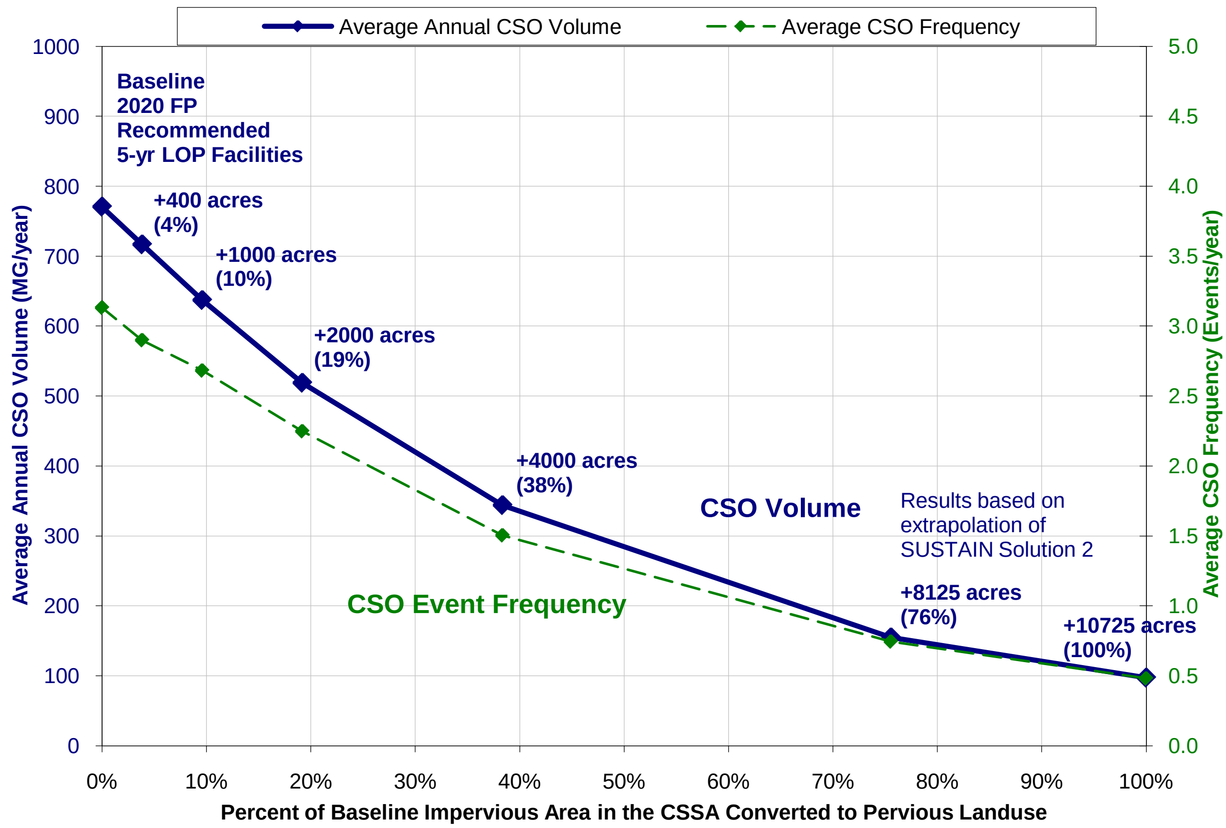


Figure 3-33. MACRO Simulation Results: Average Annual CSO Volume and CSO Frequency.

4 Potential Beneficial Impact of Green Infrastructure in the Separate Sanitary Service Area

Although the SUSTAIN pilot application was performed on an area within the CSSA, green infrastructure can have a similar if not greater impact in the Separate Sanitary Service Area (SSSA). Each of the practices simulated in SUSTAIN (rain barrels, rain gardens, block bioretention, regional bioretention, green roofs) can also be used within the SSSA and some may be even more effective. For example, the pilot SUSTAIN application assumed residential rain gardens could only be 50 square feet in size due to the small yards. To the extent that there are larger yards in the SSSA, rain gardens could also be made larger. In addition, the water quality benefits of green infrastructure will be much more significant in the SSSA because each pound of pollutant treated is a pound that would otherwise be loaded into the nearest waterway. In contrast, most pollutant runoff in the CSSA is already treated, even without green infrastructure, because it is routed to the wastewater treatment plant except when overflows occur. The results of the SUSTAIN application described in Section 3 are therefore directly relevant to what would be expected to occur within the SSSA.

In addition to the SUSTAIN results, the potential beneficial impact of green infrastructure in the SSSA was already explored as part of the 2020 Facilities Planning process. For example, Alternative A11 (or C2 in the Regional Water Quality Management Plan Update) included the adoption of the following green infrastructure elements throughout the SSSA:

- Pet litter program
- Waterfowl control program
- Control of runoff volumes beyond Wisconsin Administration Code Natural Resources (NR) 151 *Runoff Management (non-Ag only)* requirements through porous pavement and other infiltration based technologies
- Rain barrels and downspout disconnection at 15 percent of all homes in the study area
- Rain gardens/bioretention cells and downspout disconnection at 15 percent of homes in the study area
- Restoration of wetlands (converted 5 percent of all croplands to wetlands)
- Restoration of prairies (converted another 5 percent of all croplands to wetlands)

The analysis indicated that this alternative provided the greatest overall water quality benefit compared to other alternatives that did not include a comparable level of green technologies. These results are consistent with the SUSTAIN results described in Section 3 which demonstrate that green infrastructure has the potential to yield very significant benefits to both hydrology and water quality in the SSSA.

4.1 Potential Impact on Infiltration and Inflow

One issue related to implementing green infrastructure within the SSSA is its potential impact on infiltration and inflow (I/I). In general, green infrastructure could affect I/I in two ways:

1) reduce stormwater peak flow rates and runoff volumes leading to less flooding and therefore less inflow into sanitary sewers and
2) increase shallow groundwater levels leading to more infiltration into leaky sanitary sewers.

Full analysis of this topic would require a groundwater model and a sewer system model, and is beyond the scope of the current effort. In addition, there is limited peer-reviewed literature on this topic. Nevertheless, the following observations can be made given the currently available information.

Inflow and infiltration into sanitary sewers is derived from a variety of sources including inflow of stormwater through manhole covers, foundation drains, roof drains and downspouts, and illicit connections and infiltration through cracked pipes and ill fitting connections. Inflow is typically a result of stormwater runoff while infiltration is typically a result of groundwater seepage.

4.1.1 Inflow

Green infrastructure has the potential to reduce stormwater runoff volume and associated flooding and inflow to sanitary sewers. Model results from the MMSD's 2020 Facilities Plan project suggest that green infrastructure can reduce the 100-year storm peak significantly (at least 22 percent) depending on the total upstream drainage area routed to green infrastructure; reduction in peak flows is even higher for storms smaller than the 100-year storm.

4.1.2 Infiltration

Green infrastructure practices that are designed to infiltrate into the ground can cause a shift in local groundwater conditions and potentially introduce additional water into the groundwater system. The MMSD has identified 10 green infrastructure practices within the *Fresh Coast Green Solutions* publication. Of these practices, greenways, rain gardens, bioswales, porous pavement, and green alleys, streets, and parking lots have the potential to infiltrate stormwater into the ground. The amount of runoff being infiltrated and the potential effect on infiltration into the sanitary sewers will depend on a number of factors including:

- Presence of an underdrain in the green infrastructure practice – an underdrain that routes subsurface drainage to a storm sewer will eliminate a portion of the water being infiltrated into the ground and potentially into the sanitary sewer system
- Size – A green infrastructure practice that is designed to hold and infiltrate a large amount of runoff will have more potential to impact infiltration into the sanitary sewer system
- Soil type – coarse soils will allow water to move vertically through the soil profile beneath infiltrating practices thus reducing the potential for water to reach sanitary sewers located at distance away from the practice. Finer grained soils will cause water to spread out below the green infrastructure practice. Larger set back distances are needed in areas with fine grained soils, like the clayey soils within Milwaukee County.
- Location – the distance between the green infrastructure and the sanitary sewer will govern the potential for infiltrating stormwater to reach a sanitary sewer.
- Vegetation – deep rooted, native vegetation is able to transpire water from the root zone to the atmosphere.

It is possible that widespread use of infiltration practices could raise the water table during infiltrating events. However, the timing and potential impact of a higher water table would need to be evaluated through additional monitoring and modeling. In addition, the potential for green infrastructure to increase infiltration into the sanitary sewers can be eliminated by making repairs to nearby leaking sanitary sewers and laterals.

A series of four projects were completed by the MMSD in 2005 to gain knowledge on the potential for increased infiltration into leaky sanitary sewers as a result of green infrastructure practices.

Table 4-1 summarizes each of the studies and their results. Results recommend a setback of two to 10 feet between the infiltrating stormwater practice and the sanitary sewer or surrounding trench. For comparison purposes, the State of Wisconsin recommends a minimum setback of 10 feet down slope from foundations for stormwater infiltration practices.

Table 4-1. Summary of Four Green Infrastructure Projects

Project	Location	Contact	Description	Results
Porous Pavement Construction Criteria	General Mitchell International Airport (GMIA)	Stormtech	A 100 square foot test plot of EcoCreto pervious concrete was installed at the GMIA. A series of monitoring wells was installed around the plot to measure changes in water levels as water was discharged onto the pavement	It was recommended that porous pavement systems be placed at least five feet away from sewers, foundations, and vulnerable utilities
Design Guidelines to Prevent Increased Inflow/Infiltration from Stormwater BMPs	Various in District Service Area	Triad Engineering	Field experiments performed on rain gardens, downspout extenders, and rain barrels to determine their effects on I/I. From these experiments, design and construction guidelines will be developed on stormwater BMPs.	Recommends placing rain gardens at least 10 feet from sewer laterals or house foundations; using five foot long downspout extenders, with 10foot long extenders preferred; and discharging rain barrel water at least 10 feet away from foundations.
Infiltration and Inflow Study	Wet Detention-North Granville Woods Road and West Dean Road Dry Detention-West Brown Deer Road and North Lauer Street	City of Milwaukee	Flow monitored upstream and downstream of two detention basins. Data will be used in conjunction with modeling software and a model of the sanitary systems. Various actual storms will be run through the model to determine infiltration into the sanitary sewers.	There was no evidence of I/I from SW ponds, and adherence to sewer construction specifications are probably the reason. Pipes were 60-100 feet from ponds.
University of Wisconsin Milwaukee (UWM) Great Lakes Water Institute (GLWI) Green Roof and Rain Garden Evaluation	GLWI Green Roof, UWM campus-rain garden, Edgewood Avenue and Downer Avenue	UWM	Comprehensive monitoring program for the evaluation of the GLWI's green roof. Provide quantitative data on the effect of rain gardens on groundwater and underground infrastructure.	Concluded that a rain garden built at a horizontal distance of two feet or more from a sewer lateral trench will probably not lead to a significant increase in infiltration to sanitary sewer laterals.

4.2 Summary of SSSA Analysis

The SUSTAIN modeling conducted as part of this study, as well as the results of the 2020 Facilities Planning process, demonstrate that green infrastructure can have a significant positive impact on flow and water quality conditions in the SSSA. Section 5 of this report illustrates that green infrastructure can also provide a number of other environmental benefits (e.g., improved air quality), as well as social (e.g., improved aesthetics) and economic (e.g., increased property values) benefits. Based on these considerations, the potential negative impacts of green infrastructure on I/I are far outweighed by these benefits. Furthermore, any potential I/I problems can be mitigated by addressing the underlying cause of the I/I (i.e., fixing of leaking pipes), or setting infiltrating practices back from the sanitary sewer or surrounding trench.

Additional analysis is required to quantify the anticipated benefits to water quality and sanitary sewer overflow level of protection, and the associated costs, due to green infrastructure implementation in the SSSA.

5 Triple Bottom Line Analysis

5.1 Overview and Objectives of Triple Bottom Line (TBL) Analysis

MMSD understands that moving from a grey to a green and grey infrastructure system means change, and that change will require community support and strong partnerships. To build this support, it is important to report on the full spectrum of green infrastructure benefits: the social, economic, and environmental, and to show that the preferred solution hits the TBL. Indeed, social marketing studies show that to motivate change, one must first illustrate how a desired action improves people's daily lives, such as more beautiful neighborhoods, higher property values, improved safety and increased jobs. The next step in motivating change is to emphasize environmental stewardship benefits. Therefore, the objectives of this TBL analysis are to evaluate a broader range of environmental benefits alongside important economic and social benefits, and to determine the degree to which each of the green infrastructure practices contributes to the bottom line.

To facilitate the TBL analysis, the results of solution 2 from the SUSTAIN modeling of the pilot area were used. This constitutes adding 1.1 acres of porous pavement, 2.7 acres of green alleys, 2.2 acres of block bioretention, 850 rain gardens, 2.8 acres of regional bioretention, 1,300 rain barrels, 8.5 acres of roadside porous pavement, and green streets with 2.6 acres of roadside porous pavement and 0.6 acres of rain gardens. These practices drain an impervious surface area of 225 acres.

For the purposes of the quantitative TBL analysis, the team evaluated 11 TBL indicators (see Table 5-1). Air quality benefits are also qualitatively discussed, as are the benefits of green roofs.

Table 5-1. TBL Indicators Evaluated

TBL Category	TBL Indicator
Economic	Job creation
	Reduced infrastructure cost
	Reduced pumping costs
	Increased property values
Social	Improved quality of life and aesthetics
	Increased recreational opportunities
Environmental	Reduced stormwater volume
	Reduced Sediment Loading
	Increased groundwater recharge
	Increased carbon sequestration
	Reduced energy use and heat island effect

In its *Fresh Coast Green Solutions* report, MMSD highlighted 10 types of green infrastructure that, individually or in combination, could potentially improve stream water quality and reduce treatment costs for the SSSA and the CSSA. In previous sections, these practices were narrowed and simplified for the purposes of modeling. For the TBL reporting, the team analyzed 6 categories:

- Rain gardens – This category refers to the devices modeled as rain gardens in the SUSTAIN model.
- Bioretention – Bioretention was found to be more appropriate in the pilot area than wetlands, one of the MMSD green infrastructure categories. The bioretention design includes two additional MMSD green infrastructure categories: "native landscaping" (assumed to be one half of the bioretention area) and "stormwater trees" which are incorporated into the native landscaping. Therefore, these latter two MMSD categories are contained within the bioretention TBL reporting. This category also includes bioretention within green street applications.

- Bioswales –This category represents regional bioretention opportunities along transportation corridors, which mostly occur within Sewershed #CS5134#1-W.
- Rain Barrels – For ease of reporting, this term is generally used for the MMSD green infrastructure category *rainwater catchment*. Rain barrels are specifically recommended for the pilot area.
- Porous Pavement – This category includes the SUSTAIN modeling categories porous pavement, roadside porous pavement, and green street porous pavement.
- Green Alleys –SUSTAIN modeled this category directly. Although the environmental benefits are largely attributed to the porous pavement aspects, green alleys are assumed to include vegetative amenities as well.
- Note that the team was unable to identify greenway and wetland opportunities in the pilot area, so these MMSD GI categories are excluded from the detailed quantitative analysis. However, a general discussion of their quantitative benefits is provided. Green roofs were also omitted from the benefits estimation because they were not selected for solution 2.

In the sections below, for each key indicator (e.g. property value), a stacked bar chart shows cumulative, pilot area benefits from implementing all practices recommended in solution 2. The stacks indicate what portion of the benefit is attributed to the different practices. In place of a stacked chart, a cost per gallon comparison is provided under the indicator *reduced infrastructure costs*.

The TBL indicators have different time horizons for reporting. Several indicators have a one-time benefit, including increased property values and recreational amenity. Some environmental indicators are more appropriate to report in terms of recurring, annual benefits: reduced stormwater runoff, reduced sediment loading, and groundwater recharge. Other indicators have cumulative benefits that are reported over a 20-year horizon: carbon sequestration, reduced energy costs, reduced pumping costs, and reduced social costs due to job creation. Finally, reduced infrastructure costs are reported on a cost per gallon storage basis. The indicator benefits are reported below as such.

The TBL analysis begins with an evaluation of economic and social benefits, then building on previous sections of this report, the full range of environmental benefits from implementing solution 2 are evaluated. The benefits are then summarized to report on the overall potential for achieving the TBL within the pilot area.

5.2 Economic Benefits

5.2.1 Job Creation

Similar to MMSD's consideration of green infrastructure, a number of parallel management efforts throughout the United States are taking advantage of the job creation benefits of green infrastructure (as both stormwater management and, in a broader context, green energy, building, and other industries). These efforts include urban greening initiatives in Philadelphia, Pennsylvania; Lawrence, Massachusetts; and Stamford, Connecticut (USEPA 2009b; Schilling and Logan 2008; Dunn 2010) and funding for green collar jobs in several California cities (Rangwala 2008). Some programs target specific populations, like a rain barrel installation program in Cleveland that employs teens during the summer (Geiselman 2010).

Investments in any type of infrastructure are often used to create jobs, especially during periods of economic downturn. Job creation is generally estimated through the amount of spending that a project creates, and other considerations include the type of jobs created and the characteristics of the affected economy. Spending for any infrastructure improvement creates temporary jobs that may or may not remain once construction is complete. The major employment benefit of green infrastructure is that required maintenance creates a permanent need for unskilled laborers since the majority of work involves landscaping and other activities that require minimal training. Unemployed persons in poverty tend to be unskilled laborers, and the creation of recurring green infrastructure jobs provides a mechanism to bring these persons out of poverty. In turn, less funding is needed to support the unemployed through welfare and other social services. As job availability increases, crime is also expected to decrease, which further reduces the costs of fighting crime (police force, prisons, etc.).

The City of Philadelphia (2009) conducted a detailed estimate of job creation and reduction in social costs as part of their green infrastructure plan to reduce CSOs. They estimated that spending over $100 million dollars over 20 years on operation and maintenance would provide 250 permanent jobs for unskilled workers and save about $2.5 million dollars in social costs annually, or $10,000 per new green infrastructure job created per year. This estimate is based on local and national studies and accounts for the social costs of health services and crime related to persons in poverty. This is a conservative estimate as the literature review by the City of Philadelphia (2009) illustrated a range of estimates for the cost of poverty from $15,000 to $45,000 per person per year.

To estimate direct, recurring jobs created by green infrastructure for the MMSD pilot area, the annual maintenance costs for the pilot area were multiplied by the ratio of jobs per operation and maintenance (O&M) dollar spent from City of Philadelphia (2009). To be conservative, the 20-year spending estimate from the City of Philadelphia was estimated as $149 million dollars. Note, only capital costs were used in the cost-effectiveness analysis performed using the SUSTAIN model, presented in Section 3, to remain consistent with the MMSD's *Fresh Coast Green Solutions* document.

To estimate annual O&M costs from green infrastructure, annual per square foot cost estimates were used from Tetra Tech (2009) for all green infrastructure practices except for rain barrels. Tetra Tech (2009) recommends $1.5 per square foot as an annual O&M cost estimate for bioretention. This was reduced to $1 per square foot for rain gardens because these devices will be incorporated into existing landscaping on lots and the net increase in landscaping costs should be less compared to the other types of bioretention. An annual maintenance cost of $1.5 per square foot was used for bioswales as well, and a cost of $0.13 per square foot was used for green alleys and porous pavement. For rain barrels, it was estimated that an average annual maintenance cost of $3 per unit would be required based on best professional judgment. To estimate the present worth of costs over 20 years, a discount rate of 5-1/8 percent was used, which is consistent with the rate used in MMSD's 2020 Facilities Plan. This rate is used for all 20-year estimates in this TBL analysis.

Using the above assumptions, an estimated $660,000 of annual spending on maintenance costs would occur with solution 2, which would create an estimated 22 permanent jobs for unskilled workers in the MMSD pilot area. Assuming that Philadelphia's social costs are similar to Milwaukee's, this increase in jobs could result in an annual reduction of $220,000 in social costs, with a present worth of $2.7 million over 20 years. The total present worth benefits in terms of social cost reduction are shown separately for each green infrastructure practice in Figure 5-1. The large majority of job creation benefits (about 70 percent) are attributed to bioretention because a large portion of the drainage area in solution 2 would be treated with bioretention and therefore total spending on maintenance for this practice will be high relative to other green infrastructure.

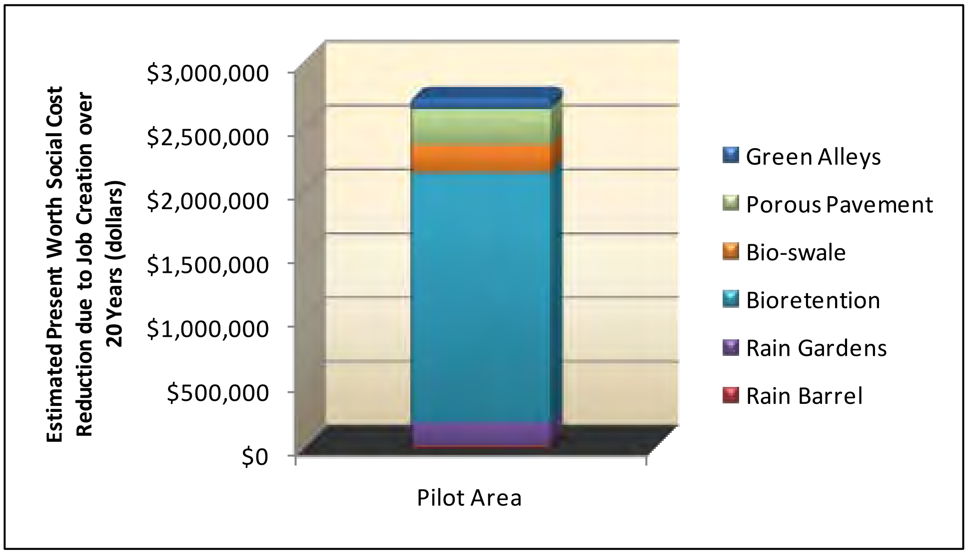


Figure 5-1. Estimated Present Worth Social Cost Reduction due to Job Creation over 20 Years.

The job creation and resulting social cost reductions estimated above account for direct permanent jobs only. It is assumed that grey infrastructure would have a negligible effect on social costs compared to green infrastructure. This assumption is based on similar assumptions used in City of Philadelphia (2009) and considers that skilled workers tend to be more mobile than unskilled workers. When skilled jobs are created, they often draw from the employed population either within or outside the pilot area. If a high degree of skilled laborer unemployment exists, then spending on deep tunnel maintenance may also provide a decrease in social costs due to reduction in unemployment benefits. Social cost estimates for unskilled workers account for much greater costs in addition to unemployment (including Medicaid, food stamps, health and social services, public housing, community development, homeless expenditures, and judicial and institutional services); therefore, the savings in social costs due to permanent green infrastructure jobs is generally expected to be much greater than for permanent jobs created by grey infrastructure. Construction spending is also expected to produce additional skilled and unskilled jobs on a temporary basis although this would occur for both green and grey infrastructure.

The permanent jobs created from green infrastructure O&M can also lead to an increase in jobs through supporting industries and spending by the newly employed. Over time, construction in green stormwater infrastructure, when combined with other construction in the green sector, can produce a cumulative boost in the overall demand for permanent skilled and unskilled labor. Moreover, as the workers spend their income, additional indirect jobs would likely be created in retail, service, and other related industries. As mentioned above, social costs are reduced through unskilled job creation, and money saved can be redistributed to other social needs that could stimulate the economy. Overall, jobs created through green infrastructure provide an economic value added beyond the jobs themselves.

Job creation benefits can be estimated through modeling, and economic models can be used to estimate job creation from green infrastructure and similar spending. For example, Pennsylvania Department of Labor and Industry (2010) used the economic model IMPLAN and estimated that 115,000 jobs would be created from a $10 billion dollar investment in renewable energy, energy efficiency, clean transportation, and pollution prevention and environmental cleanup services. About two-thirds of these jobs would be directly created from the investment, and the remaining jobs would be created from industries that provide products and services for the green sector and the newly employed.

5.2.2 Reduced Infrastructure Costs

Green infrastructure provides an opportunity to reduce the costs of grey infrastructure. As green infrastructure provides infiltration, evapotranspiration, and storage, it reduces the need to control stormwater runoff after it reaches the combined sewer system, which in turn reduces the need to maintain existing or to build new grey infrastructure. Several cities have already implemented green infrastructure on a large scale and have experienced significant cost savings. Green infrastructure within the City of Philadelphia has reduced CSO inputs by a quarter billion gallons and has saved the city an estimated $170 million. In addition to these cost savings, additional savings could be expected from reduced upkeep and maintenance costs for pipe networks and treatment plants. Another cost-benefit analysis by the City of Seattle estimated that natural drainage designs can reduce street drainage costs by about 24 to 45 percent compared to traditional designs (Seattle Public Utilities 2008).

The decision to expand or build new grey infrastructure may depend on the absolute volume of runoff reduced and how well green infrastructure handles the larger storm events that would cause additional overflows and lead to the need for expansion. This threshold is difficult to predict and depends on both the current capacity as well as the decision-making process that would lead to planning an expansion.

To demonstrate the reduced infrastructure costs, independent of future decision-making, these benefits were estimated in terms of cost per gallon of water controlled. An estimate of how green infrastructure reduces the need for grey infrastructure capacity could not be quantified with available information. As a surrogate for this volume, the green infrastructure storage volume was used. This method assumes that the volume entering the deep tunnel would increase by the green infrastructure design volume if the green infrastructure did not exist. This assumption does not account for losses between the green infrastructure site and the deep tunnel, and this volume would likely be routed to the treatment plant during the design storm and only affect deep tunnel capacity during larger storm events. If both types of infrastructure were located at the source of runoff, the cost per gallon would be more comparable. The infiltration rates of the devices compared to the flow rate into the deep tunnel also are factors in the effective storage volume but could not be accounted for in this analysis. Finally, this analysis does not account for the reduced treatment plant costs attributable to green infrastructure. Although some assumptions may attribute more benefit to either grey or green infrastructure, the overall intent of this analysis was to provide a conservative estimate of green infrastructure benefits.

The capital cost of deep tunnel construction, design, and engineering was estimated by MMSD to be $2.42/gallon based on past project experience. The O&M costs are expected to be about 1 percent of the capital cost, or $0.02/gallon (HNTB 2004). The storage volume for the green infrastructure was estimated based on the depth and porosity assumptions used in SUSTAIN (Section 3). The green infrastructure costs for solution 2 range from $0.50 to $2.00 per gallon in capital costs and $0.10 to $2.00 per gallon in O&M costs. These costs are independent of the amount pumped per year, which is addressed in the following section.

Figure 5-2 compares the capital, 20-year present worth O&M, and total present worth costs per gallon of storage between green and grey infrastructure. The deep tunnel costs are shown as redlines indicating the capital costs and total costs (capital plus 20-year present worth O&M). Across capital, O&M, and total costs, green infrastructure is estimated to have a cost per gallon of storage less than the comparable deep tunnel cost, resulting in an overall savings in infrastructure costs.

Rain barrels and rain gardens have the highest cost per gallon, and their total costs per gallon are slightly less than the total deep tunnel costs. Rain barrels have a high upfront cost and comparatively smaller maintenance cost per gallon of storage. Rain gardens have high maintenance costs relative to bioretention and other similar practices because they require vegetation maintenance but do not have the additional storage provided by an underdrain.

Porous pavement would provide the greatest cost savings related to storage volume on a per unit basis because it is estimated to have the lowest total present worth cost at $0.6 per gallon of storage, a savings of over a $2 per gallon or a 77 percent reduction in storage costs. Green alleys are also estimated to provide considerable cost savings at about $1.80 per gallon or a 66 percent reduction in costs. Both practices provide considerable storage with minimal maintenance costs. Therefore, although implementation of green infrastructure alone is not likely to be able to eliminate overflows in Milwaukee (see Section 3), it may reduce or delay the need for the construction of an additional deep tunnel and may also reduce the volume required for that tunnel, reducing future capital and O&M costs.

The results are different than the SUSTAIN results in Section 3.6.5, which indicate that rain gardens are most cost-effective for volume reduction. The SUSTAIN analysis accounted for size and frequency of storm events within a 10-year period; since rain gardens are best at reducing runoff during small storm events, which are the most frequent events, these practices were most cost-effective across the 10-year period. However, when comparing green infrastructure to deep tunnel costs on a per unit storage basis, porous pavement is most cost-effective among the green infrastructure practices.

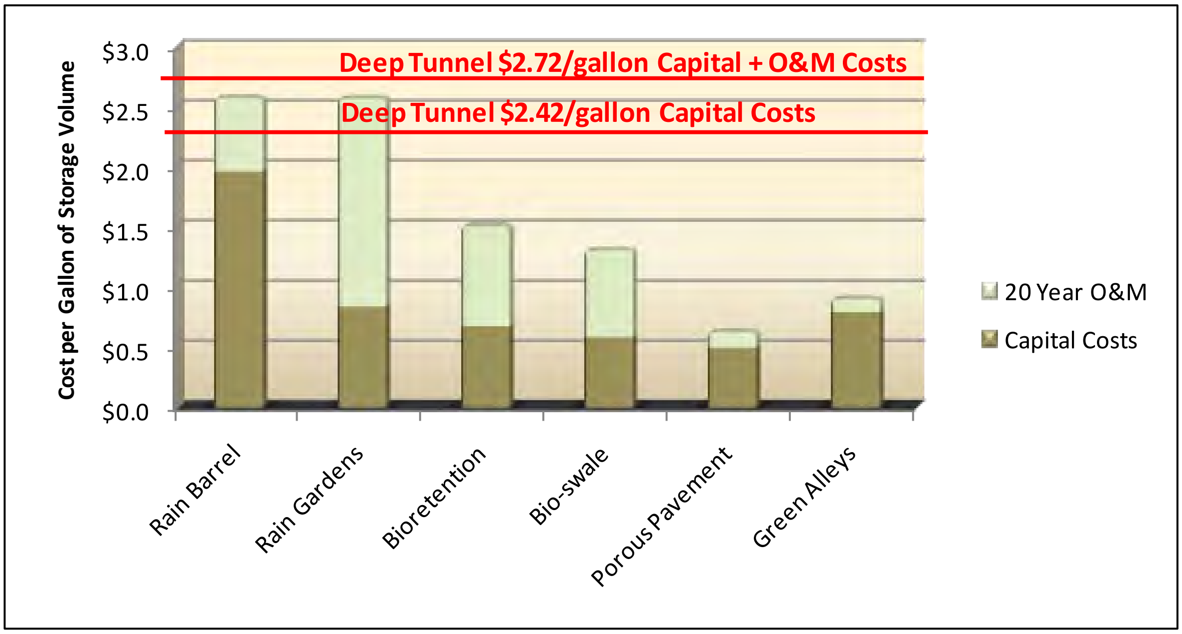


Figure 5-2. Estimated Present Worth Infrastructure Costs per Storage Volume over 20 Years.

Additional cost savings can be achieved on a site-specific basis, and the greatest cost savings can be realized by using the topography of the existing landscape. Even within an urbanized area, opportunities for green infrastructure can be identified where the existing drainage patterns minimize retrofit costs and provide a cost-effective means for pollutant removal and hydrologic control. Using existing low areas, by definition, is expected to provide a costs savings because it uses an existing resource instead of building an entirely new structure. The advantages of green infrastructure, when implemented correctly, are that it takes advantage of these existing resources. Design considerations also are not limited to the green infrastructure practices considered in this analysis. For example, existing underused parking lots can be retrofitted to hold stormwater with minimal additional infrastructure.

5.2.3 Pumping Costs

Similar to the reduction in infrastructure costs, green infrastructure reduces the need for deep tunnel pumping. These benefits are most evident during small storms when the deep tunnel is not at capacity and any reduction in stormwater runoff will reduce the need for pumping. During some larger storm events, the volume controlled by green infrastructure may not be great enough to reduce deep tunnel pumping. However, on an annual basis, green infrastructure is expected to provide an overall savings in tunnel pumping costs.

As reported in the Section 3 recommendations, solution 2 is expected to reduce tunnel pumping by about 129 MG during a typical year. The average pumping cost is estimated as $28.8 per gallon (HNTB 2009).

A present worth of $46,000 in pumping cost savings from the green infrastructure pilot study area was estimated over 20 years. To estimate the portion of cost savings attributed to each practice, the total present worth was multiplied by the portion of annual volume reduction provided by each green infrastructure practice in solution 2. Figure 5-3 illustrates that green alleys, porous pavement, and bioretention would provide the greatest reduction in pumping costs. These practices provide the greatest cost savings because they are applied to a greater extent of the pilot area compared to other green infrastructure. This reflects both the larger extent of opportunities in the pilot area for these practices as well as their volume reduction cost-effectiveness compared to other green infrastructure.

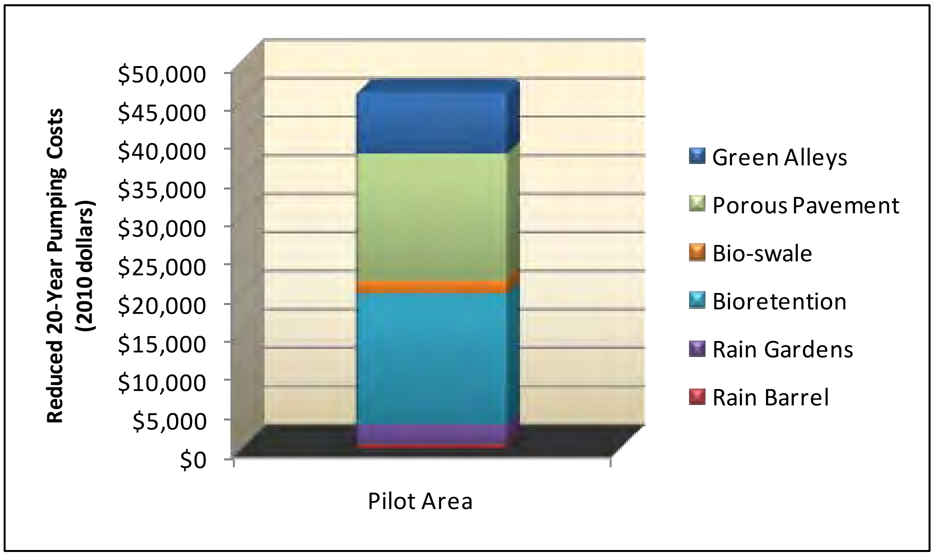


Figure 5-3. Estimated Present Worth Tunnel Pumping Cost Reduction over 20 Years.

Additional benefits can be realized from reduction in tunnel pumping due to green infrastructure. Reduction in tunnel pumping can reduce energy use and result in a reduced carbon footprint for the pilot area. When testing the application of low impact development to 50 percent of its study area, the City of Philadelphia (2009) estimated that reduced emissions from pumping and other activities related to grey infrastructure resulted in nearly $34 million for energy savings, over $21 million in social benefits for reduced CO_2 emissions, and over $46 million for reduced net damages from SO_2 and NO_x emissions. Later sections of this analysis provide more discussion of carbon sequestration and air quality benefits related to green infrastructure.

5.2.4 Property Values

A number of studies have estimated the effect that green infrastructure and similar practices have on surrounding property values. Many aspects of green infrastructure can increase property values, including improved aesthetics, drainage, recreational opportunities, and any aspect that would reduce the owner's or tenant's costs (rainwater harvesting, reduced heat island effect, etc.). In fact, the property value benefits are closely tied with the social and environmental benefits discussed in separate sections below. The best documented benefit is the effect that the additional plants and trees associated with green infrastructure have on property value due to their aesthetic nature. Increases in property value not only benefit individual property owners, but also can lead to increased tax revenue and general economic improvement, including increased jobs.

Table 5-2 summarizes the recent studies that have estimated the effect that green infrastructure or related practices have on property values. The majority of these studies addressed urban areas, although some suburban studies are also included. The studies used statistical methods for estimating property value trends from observed data.

Table 5-2. Studies Estimating Percent Increase in Property Value from Tree Planting, Low Impact Design with Vegetation, or Community Gardens.

Source	Percent increase in Property Value	Notes
Ward et al. (2008)	3.5 to 5%	Estimated effect of LID on adjacent properties relative to those farther away in King County (Seattle), WA.
Shultz and Schmitz (2008)	0.7 to 2.7%	Referred to effect of clustered open spaces, greenways and similar practices in Omaha, NE.
Wachter and Wong (2006)	2%	Estimated the effect of tree plantings on property values for select neighborhoods in Philadelphia.
Anderson and Cordell (1988)	3.5 to 4.5%	Estimated value of trees on residential property (differences between houses with five or more front yard trees and those that have fewer), Athens-Clarke County (GA).
Voicu and Been (2008)	9.4%	Refers to property within 1,000 feet of a park or garden and within 5 years of park opening; effect increases over time
Espey and Owasu-Edusei (2001)	11%	Refers to small, attractive parks with playgrounds within 600 feet of houses
Pincetl et al. (2003)	1.5%	Refers to the effect of an 11% increase in the amount of greenery (equivalent to a one-third acre garden or park) within a radius of 200 to 500 feet from the house
Hobden, Laughton and Morgan (2004)	6.9%	Refers to greenway adjacent to property
New Yorkers for Parks and Ernst & Young (2003)	8 to 30%	Refers to homes within a general proximity to parks

After taking the midpoint of each reported range, the median increase in property value amongst these studies was 4 percent. This value is similar to the assumption of 3.5 percent used by the City of Philadelphia (2009), which consulted some but not all of the above studies. In studies that considered the distance from an improvement at which property value increases are realized, the distances considered ranged from 200 to 1,000 feet, with a median of about 600 feet. Based on these references, the property value increase estimated for the pilot area assumed that green infrastructure would increase property values by 4 percent if a property line came within 600 feet of a potential green infrastructure opportunity.

A spatial analysis of the full opportunity extent indicated that all parcels within the sewershed are within at least 600 feet of an opportunity for green infrastructure. If all identified opportunities were implemented, all parcels in the pilot area would likely increase in property value.

Median property values were estimated as $1 million per acre in the pilot area. However, the parcel tax values indicated that property values in sewershed CS5134#1-E tend to be about 60 percent less than values in the other three sewersheds. Therefore, property values for the other sewersheds were estimated as $1 million per acre and property values for sewershed CS5134#1-E were estimated as $400,000 per acre.

To estimate the property value increase due to solution 2, eligible parcel acres were scaled down based on the proportion of area in each sewershed compared to the full opportunity extent of the practices. The property value of this parcel area was calculated based on the above assumptions. Then, four percent of this property value was estimated as the green infrastructure benefit, and this benefit was attributed to each green infrastructure practice proportionally by surface area. This is a conservative estimate as literature is not readily available on cumulative benefits of multiple green amenities in a similar location. Rain barrels were excluded from this analysis because they were not expected to induce property value increases due to aesthetic changes.

The property value increases expected from solution 2 are estimated to total $2.7 million across all affected parcels. Figure 5-4 presents the estimated property value increase for the pilot area by green infrastructure practice. Although a large portion of the property value increase is attributed to porous pavement, more of the increase should be attributed to porous pavement within green streets due to the associated vegetation amenities.

Bioretention is also expected to provide a large portion of the property value increases due to both the extent of opportunity in the pilot area and the greater aesthetic amenities it provides compared to other green infrastructure. Although the relative differences in property value across green infrastructure are largely theoretical as noted above, the general increase of four percent is well supported by literature and represents a significant benefit resulting from Solution #2. This property value increase represents a onetime increase in property value that is expected to occur within a few years of green infrastructure implementation.

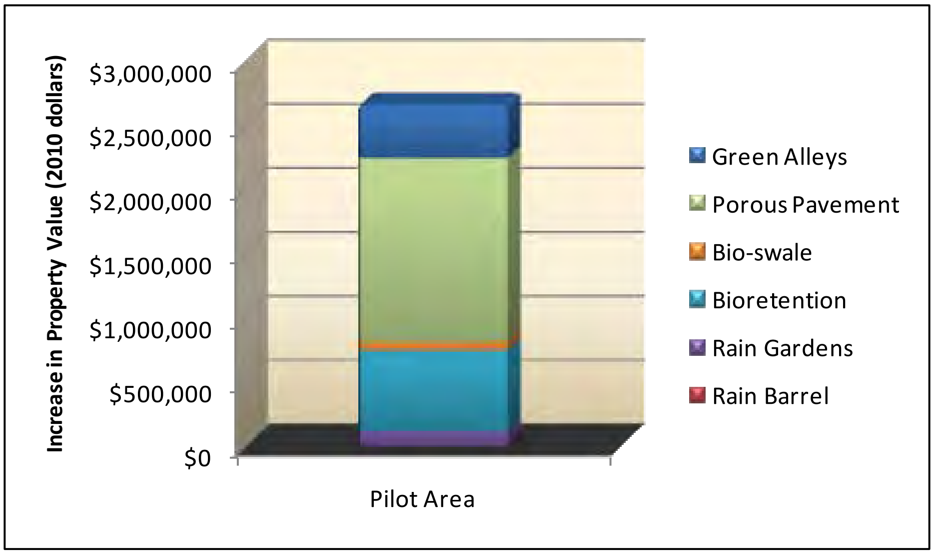


Figure 5-4. Total Increase in Property Value in Pilot Area by Practice.

Some studies have used statistical techniques and other methods to estimate the value of green infrastructure and similar practices beyond aesthetic values. Braden and Johnston (2004) reviewed a number of studies that estimated values for the following benefits: reduced frequency and extent of flooding, reduced pollution, improved water quality, improved in-stream biological integrity and stream aesthetics, and increased groundwater recharge. For example, Streiner and Loomis (1995) estimated that the value of stormwater management and restoration can increase property values from 3 to 13 percent due to amenities such as reduced flood exposure, stream bank stabilization and revegetation, debris removal, and other benefits. These and other benefits of green infrastructure are discussed and quantified separately in the sections below.

5.3 Social Benefits

5.3.1 Quality of Life and Aesthetics

There is a large body of literature indicating that green space makes places more inviting and attractive and enhances people's sense of well being. People living and working with a view of natural landscapes appreciate the various textures, colors, and shapes of native plants, and the progression of hues throughout the seasons (Northeastern Illinois Planning Commission 2004). Birds, butterflies, and other wildlife attracted to the plants add to the aesthetic beauty and appeal of green spaces and natural landscaping. Attention restorative theory postulates that exposure to nature reduces mental fatigue, with the rejuvenating effects coming from a variety of natural settings, including community parks and views of nature through windows; in fact, desk workers who can see nature from their desks experience 23 percent less time off sick than those who cannot see any nature, and desk workers who can see nature also report a greater job satisfaction (Wolf 1998).

A large study of inner-city Chicago found that one-third of the residents surveyed said they would use their courtyard more if trees were planted (Kuo 2003). Moving from the hypothetical to real, residents living in greener, high-rise apartment buildings reported significantly more use of the area just outside their building than did residents living in building with less vegetation (Hastie 2003; Kuo 2003).

One national study used a survey questionnaire to investigate public perceptions about the role of trees in revitalizing business districts (Wolf 1999). The study found that amenity and comfort ratings are approximately 80 percent higher for a tree-lined sidewalk compared to a non-shaded street. Quality-of-product ratings were 30 percent higher in districts having trees over those with barren sidewalks. Another study assessed how green space amenity values relate to customers' price valuation, and survey participants consistently priced goods significantly higher in landscaped districts. Prices on average were 12 percent higher in landscaped versus non-landscaped areas (Wolf 1999). In a survey of one community, 74 percent of the public preferred to patronize commercial establishments whose structures and parking lots have trees and landscaping (Urban Forest Values 1998).

Finally, research shows that green space can influence safety and crime. In one study, researchers examined the relationship between vegetation and crime for 98 apartment buildings in an inner city neighborhood and found the greener a building's surroundings are, the fewer total crimes (including violent crimes and property crimes), and that levels of nearby vegetation explained 7 to 8 percent of the variance in crimes reported by building (Kuo 2001a). In investigating the link between green space and its affect on aggression and violence, 145 adult women were randomly assigned to architecturally identical apartment buildings but with differing degrees of green space. The levels of aggression and violence were significantly lower among the women who had some nearby nature outside their apartments than those who lived with no green space (Kuo 2001b). The stress reduction effects of trees are likely to also have the effect of reducing road rage and improving the attention of drivers (Wolf 1998; Kuo 2001a). Generally, if properly designed, narrower, green streets decrease vehicle speeds and make neighborhoods safer for pedestrians.

It was assumed that these quality of life and aesthetic benefits are reflected in the increased property values of an area, as reported in Figure 5-5. Therefore property values can be seen as an integrating indictor as they reflect, in part, people's enhanced sense of well being and their willingness to pay for it.

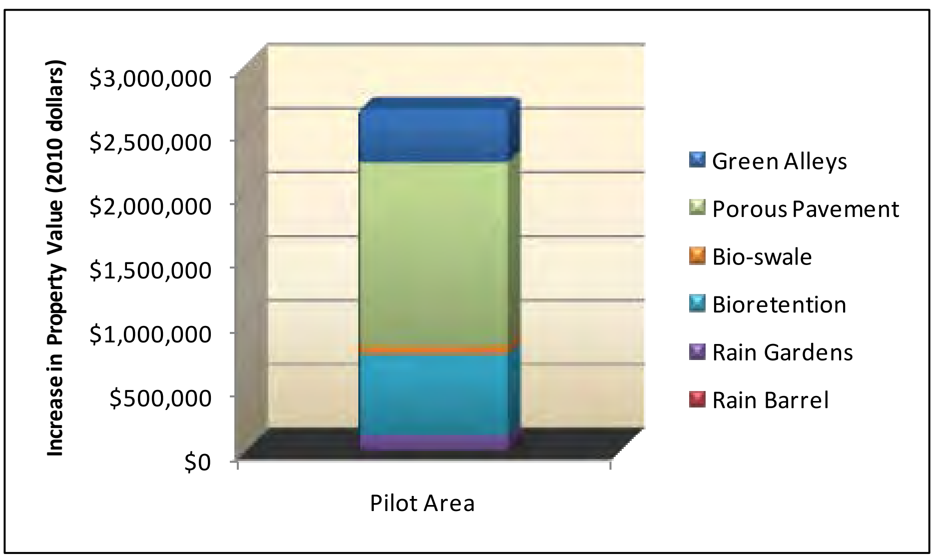


Figure 5-5. Total Increase in Property Value in Pilot Area by Practice.

5.3.2 Recreational Amenity

Green infrastructure can provide a number of recreational amenities and opportunities:

- Trails and picnic areas along restored streams, riparian buffers, and non-streamside greenways
- Green alleys, green streets, and greenways that provide more connectivity and pedestrian friendly environments
- Green spaces become outdoor rooms and public amenities

All these green spaces increase people's sense of well being, safety, and aesthetic environment, and draw people outside to picnic, walk, bike, jog, bird watch, etc. Interestingly, the mere presence of nature influences people's perception and motivation regarding recreation. Research has found that people make more walking trips when they are aware of natural features in the neighborhood and judge distances to be greater than they actually are in less green neighborhoods (Wolf 2008).

As an indicator of potential recreational amenity, the team totaled the new greened area associated with green alleys and bioretention in the pilot study area. Although opportunities for greenways and wetlands were not identified in the pilot area, these green infrastructure practices are strongly linked to improved recreational amenities and should be targeted for other sewersheds in the region, as feasible. Figure 5-6 indicates that green alleys and bioretention would provide an increase of 11 acres in recreational area, with bioretention providing about two-thirds of the increase.

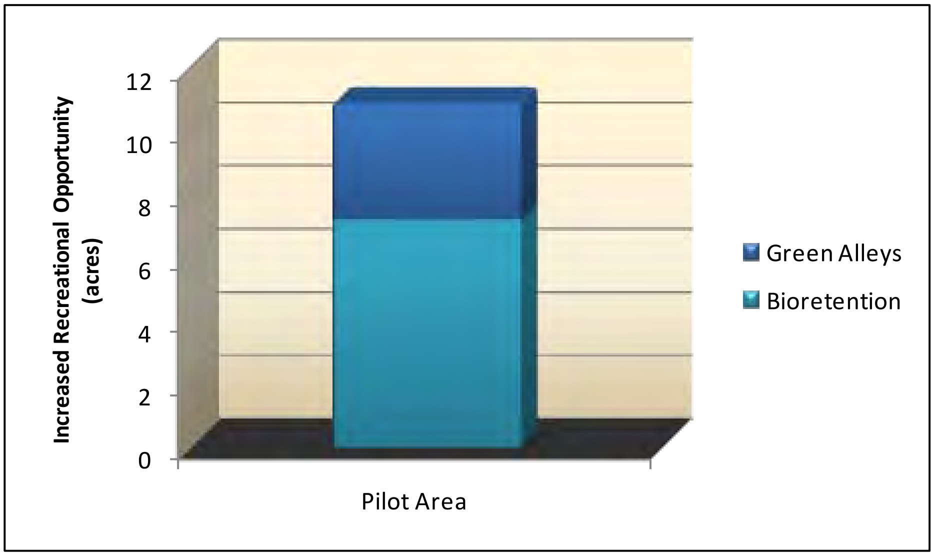


Figure 5-6. Total increase in Recreational Opportunity in Pilot Area by Practice.

5.4 Environmental Benefits

5.4.1 Reduced Stormwater Runoff

The green infrastructure practices work to effectively reduce stormwater runoff *volume*. Many of the practices are designed to capture (and treat) the runoff from smaller storm events. While this volume reduction is a smaller percentage of the overall runoff during extreme events (when CSOs may be occurring), the storage, infiltration, evaporation, and slow release of the stormwater from these distributed systems better replicate runoff and time of concentration from the predevelopment conditions. Importantly, depending on the level of implementation, this could potentially slow the timing and peak of stormwater reaching the grey collection system and thus minimize the risk of overflow from the CSO system.

The team used the SUSTAIN modeling results to quantify the reduction of stormwater runoff: 435 acre-feet per year (see Figure 5-7). The greatest runoff benefits are attributed to porous pavement and bioretention. These results are a function of the extent of opportunity and effectiveness of these practices.

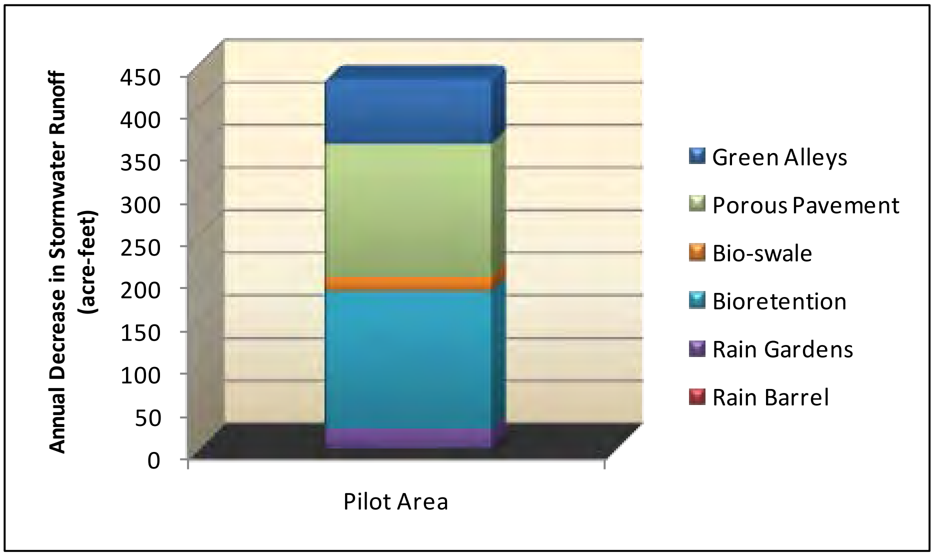


Figure 5-7. Annual Decrease in Stormwater Runoff in Pilot Area by Practice.

5.4.2 Reduced Sediment Loading (as a surrogate for water quality parameters)

Although most flow to the combined sewer system is treated at the Jones Island Water Reclamation Facility (WRF), sediment carried into the combined sewer system from land disturbance and post-construction runoff can accumulate in and potentially clog the collection system (impacting operations), decrease the quality of the CSOs when they do occur, increase the amount of sludge to be managed at the WRF, pose operational challenges at the WRF, and increase WRF operational costs. Moreover, attached to the sediment are other parameters of concern: bacteria, phosphorus, metals, and other organic matter. Since CSOs are dominated by stormwater, reduced sediment loading to the CSO system improves the overall quality of the overflow and helps mitigate concomitant environmental impacts. The team used the SUSTAIN model results to estimate reductions in sediment loading, which in turn serves as an overall indicator of water quality benefits.

Figure 5-8 presents the annual reduction in sediment loading by practice. The total sediment load reduction by Solution #2 is estimated as 68 US tons per year. Since the majority of sediment loading occurs during larger storm events, the green infrastructure yields sediment reductions both in CSOs and in water that must be treated at the treatment plant. The greatest sediment reduction benefits are attributed to porous pavement and bioretention. These results are a function of the extent of opportunity and effectiveness of these practices.

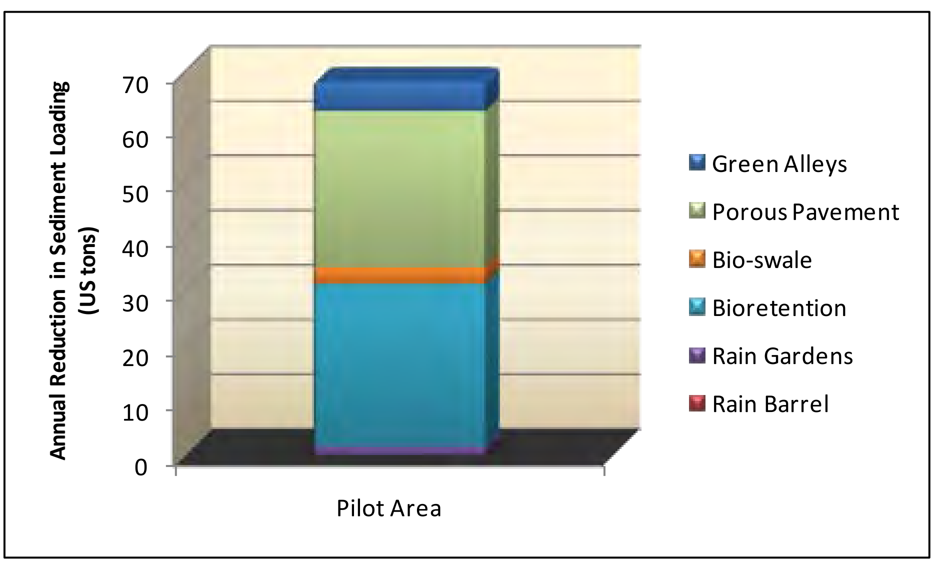


Figure 5-8. Annual Reduction in Sediment Loading in Pilot Area by Practice.

5.4.3 Groundwater Recharge

Stormwater that is retained and/or infiltrated contributes to soil moisture, groundwater replenishment, and stream base flow. The *Wisconsin Storm Water Manual* - Overview and Screening Criteria (Lowndes 2000) states,

> Storm water runoff volumes should be kept as close to pre-development conditions as practical. This requires maintaining the natural infiltration capacity of land development sites or creating infiltration zones to handle runoff from impervious area. Maintaining infiltration capacity will help maintain stream base flows and limit the duration and frequency of bank-full flood flows for streams.
>
> Groundwater should be protected against contamination from polluted storm water. Direct infiltration of storm water should be restricted to runoff from relatively clean areas such as lawns, rooftops, sidewalks, and driveways.

The SUSTAIN modeling results were used to estimate groundwater recharge benefits. The model routed rainwater through the green infrastructure practice. For each practice, there was a seepage estimate of 0.15 inch per hour, representing the low infiltration soils that characterize the pilot area.

Figure 5-9 presents the annual increase in groundwater recharge attributed to the green infrastructure. Across the entire pilot area, Solution #2 is estimated to provide a groundwater recharge increase of 406 acre-feet per year. The greatest groundwater recharge benefits are attributed to porous pavement and bioretention. These results are a function of the extent of opportunity and effectiveness of these practices.

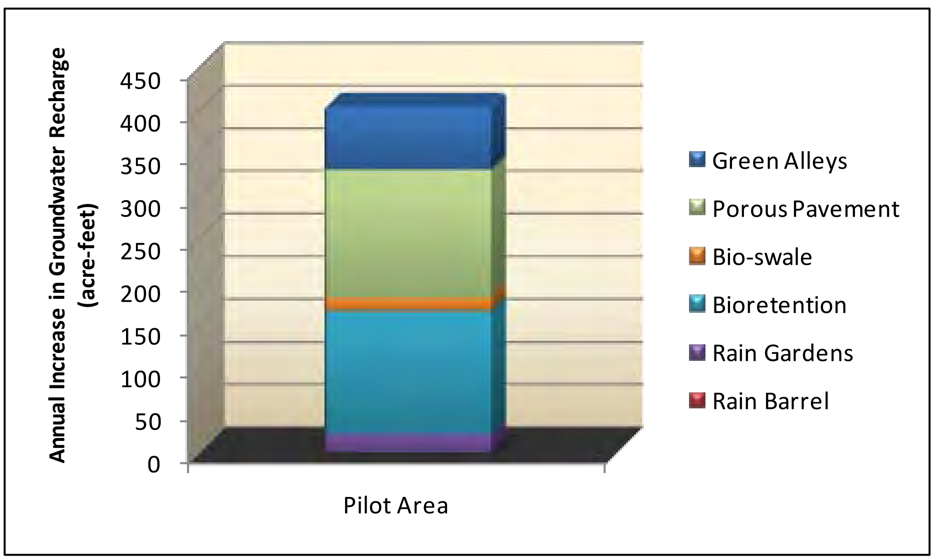


Figure 5-9. Annual Increase in Groundwater Recharge in Pilot Area by Practice.

5.4.4 Carbon Sequestration

According to the study, *Milwaukee, Urban Tree Effects and Values* (USFS 2008), there are 3,377,000 existing trees in Milwaukee alone, with a tree canopy covering 13,374 acres, or 21 percent of the City. These trees reduce the amount of carbon in the air by removing (sequestering) CO_2 from the air, storing the carbon in new growth as cellulose, and then releasing oxygen back into the air. The existing urban forest in Milwaukee sequesters 15,500 tons per year of carbon, with an associated value of $321,000 (USFS 2008). The unit value of carbon sequestration was drawn from a study by Samuel Fankhauser, the *Social Cost of Greenhouse Gas Emissions* (Fankhauser, 1994). In this latter report, the value per ton of carbon sequestered was based on estimated damages avoided (e.g., to forestry, agriculture, water, energy, etc. (David Nowak, USFS, primary author of *Milwaukee Urban Tree Effects and Values*, personal communication with K. Brewer, September 30, 2010)). This annual carbon removed from the air by the urban forest is equivalent to the annual carbon emissions from 260,000 automobiles or 131,000 single family homes (USFS 2008).

In addition to trees, engineered green infrastructure – such as green roofs, bioretention areas, bioswales, and rain gardens – also sequester CO_2 (DEFRA 2007; City of Philadelphia 2009); however, based on the team's literature review, the quantitative benefits of such practices and the rule of thumb estimates used to include these practices in green infrastructure CO_2 sequestration benefits have not been well documented.

To estimate the carbon sequestration benefits from implementing Solution #2, the team derived a per acre carbon sequestration value from the Milwaukee urban tree study by dividing the total estimated carbon sequestered (15,500 tons/year) by the acres of tree canopy (13, 374) to yield a per acre reduction of 1.16 tons per greened acre per year. This unit benefit was applied to the acres of bioretention, bioswales, and rain gardens in Solution #2. As noted above, there is some uncertainty around the exact quantifiable benefits associated with the engineered green infrastructure practices. Therefore, to be conservative, the team assumed that an acre of green infrastructure is 75 percent as effective in carbon sequestration as an acre of tree canopy, which yields estimated 0.87 ton of CO_2 removed per acre of green infrastructure per year. The total carbon sequestration benefits for the pilot area reflect a 20-year horizon. Figure 5-10 indicates that the greatest benefit from carbon sequestration is achieved through bioretention, with an overall pilot area reduction of 156 tons of carbon dioxide avoided under Solution #2. This is equivalent to the annual carbon emissions from 2,652 automobiles or 1,318 single family homes.

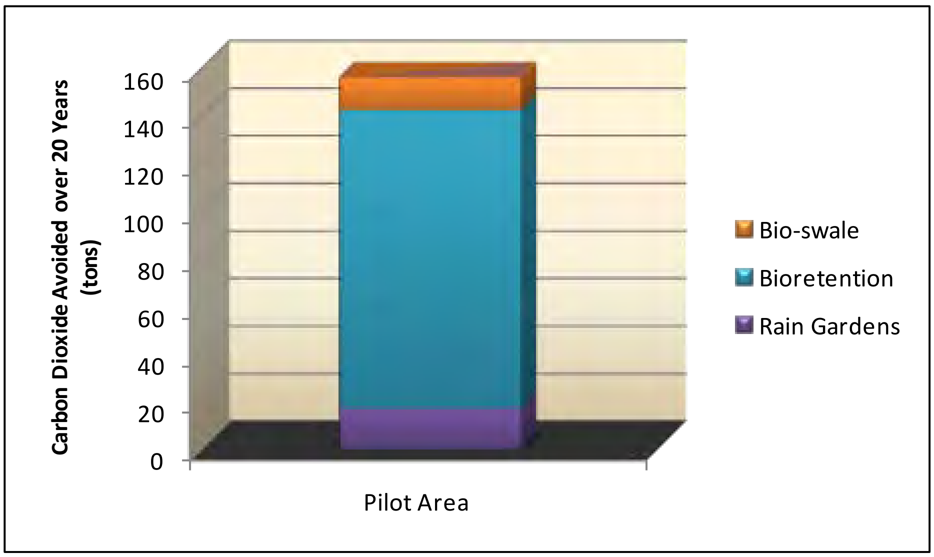


Figure 5-10. Carbon Dioxide Avoided over 20 Years in Pilot Area by Practice.

5.4.5 Reduced Energy Use and Reduced Heat Island Effect

Trees and other vegetation planted near buildings can affect energy consumption by shading, providing evaporative cooling, and blocking winter winds. Trees generally reduce building energy consumption in the summer months, and can either increase or decrease energy use in the winter depending on the location of the trees. The study of urban forest in Milwaukee indicates that the location of trees provide a significant energy savings in summer cooling (11,896 Megawatt-hours), but an actual increase in energy needed for heating in the winter (an additional 17,080 Million British Thermal Units) (USFS 2008). Despite the increase in heating costs, trees in Milwaukee were estimated to reduce overall energy-related costs from residential buildings by $864,000 annually (USFS 2008; using 2002 prices).

Buildings with green roofs have insulating effects that can reduce the penetration of summer heat and the escape of interior heat in winter (Banting 2005). They also can provide important evaporative cooling effects that decrease energy needed for heating and cooling. Based on a study in Chicago, green roofs can lower heating and cooling demands up to 30 percent (Gilligan 2005). These reduced energy demands in buildings result in energy savings for households and businesses and a decrease in the region's carbon footprint. Further energy savings can be generated by mature tree canopy in the region. Such tree canopy can reduce air temperature by about 5 to 10 degrees F, thus helping mitigate the heat island effect and lower the temperature in nearby buildings (Urban Forest Values 1998.)

To estimate potential energy savings from bioretention and rain garden areas, the project team used the estimated energy savings in the Milwaukee urban tree study (11,875,000 kWh saved from reduced cooling) divided by the City's 13,374 acres of tree canopy to generate a savings per greened area: 888 kWh/acre/year. The savings assumption was reduced by half to 444 kWh/acre/year when applied to rain gardens and bioretention to account for the limited shading provided by these practices compared to green roofs and other plantings that provide more direct shade to roofs. These benefits were summed over a 20-year horizon.

As noted above, the USFS study of the benefits of Milwaukee's urban forest found that trees in the city actually increase heating costs (due to the types and locations of trees and their shading effects). For the purposes of the TBL analysis, the team assumed that the green infrastructure would have a neutral impact on heating costs through optimizing the location of rain gardens and bioretention areas. For example, one guidance document recommends placing trees and other green infrastructure around buildings such that they provide shading in the summer and allow heat gain in the winter using strategies such as the planting of deciduous trees rather than evergreens (Bonestroo 2007).

Figure 5-11 indicates that the greatest benefit from reduced energy use is achieved through bioretention, with a reduction of 3,200 kWh/year under solution 2, or 64,000 kWh over 20 years projected to result from bioretention applied in the pilot area. Power rates are estimated to range between $0.09 for commercial and industrial properties and $0.13 per kWh for residential properties (USEIA 2010). When this cost range is applied over 20 years, the resulting present worth cost savings for both bioretention and rain gardens is estimated at approximately $3,900 to $5,700 for the pilot area.

Green roofs were not identified as among the most cost effective green infrastructure practices based on stormwater volume and peak reduction. However, green roofs have many additional potential benefits beyond stormwater management, including reducing cooling and heating energy demand by up to 30 percent and reducing the overall temperature in the city. For more information on the benefits provided by green roofs, see Section 5.5.2.

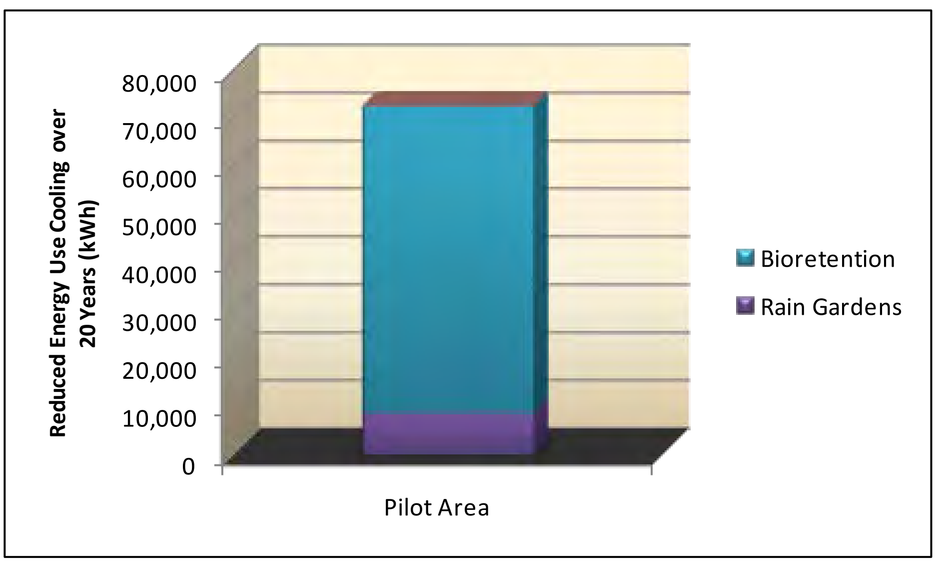


Figure 5-11. Reduced Energy Use Cooling over 20 Years in Pilot Area by Practice.

5.5 Other Benefits (Qualitative)

5.5.1 Air Quality

Poor air quality can affect human health (e.g., cause or worsen respiratory diseases) and damage other environmental resources such as water, aquatic life, and trees. Urban trees can help improve air quality by reducing air temperature, removing pollutants from the air, and reducing energy consumption (Nowak, David). The Milwaukee urban forest study estimated that trees and shrubs in the City remove 496 tons of air pollution annually, based on field data as well as recent pollution and weather data (USFS 2008). This is equivalent to 74 pounds of pollution removed each year per acre of the City's tree canopy.

The 496 tons of pollution removed includes (USFS 2008):

- Carbon monoxide equivalent to emissions from 21 automobiles and 89 single-family houses;
- Nitrogen dioxide equivalent to emissions from 4,250 automobiles and 2,830 single-family houses;
- Sulfur dioxide equivalent to 49,800 automobiles and 834 single-family houses; and
- Particulate matter (less than 10 microns) equivalent to 342,000 automobiles and 33,000 single-family houses.

Based on these findings, adding acres of trees and shrubs through green infrastructure is expected to proportionally offset pollutant emissions.

5.5.2 Green Roofs

Although green roofs were not included in the Solution #2 bundle of most cost effective BMPs, given their multiple TBL benefits, they should be considered as part of the green infrastructure menu of options in reducing overflows in Milwaukee. Some of the benefits estimated in this section can be estimated on a unit basis. For these benefit categories, per unit benefits are estimated below, using the methods and assumptions outlined previously in this section.

- Job creation: reduced social cost per acre of $9,000 per year.
- Carbon sequestration: 0.87 tons/acre/year of atmospheric carbon reduced.
- Reduced energy use cooling: 16,988 kWh/acre/year of energy use reduced.

Additional TBL benefits provided by green roofs are outlined in the following bullets.

Quality of Life

- Enhances aesthetic appearance of a building.
- Creates peaceful, stress-relieving environments.
- Reduces noise transmission into the building by up to 40 decibels. The exact level of noise reduction depends on the thickness of the growing media (Gilligan 2005).

Economic Benefits

- Increases roof life up to 200 percent (Gilligan 2005).
- Insulating effects of added plants and substrate material reduce the penetration of summer heat and the escape of heat in the winter, thus increasing energy efficiency (Banting, 2005).
- Reduces maximum temperatures and reduces temperature variation by half, contributing to energy efficiency (Banting, 2005).
- Widespread heat reduction measures, such as green roofs, can easily lower a city's temperature by five degrees (Gilligan 2005). This can produce a reduction in heat island effects and the associated air conditioning demand.
- Lowers overall heating/cooling cost up to 30 percent (Gilligan 2005).

- Increases property value.
- Generates less stress on HVAC systems and improves longevity.
- Can provide potential government enticements for new businesses and residents.
- Increases property value.

Environmental Benefits

- Retains well over 50 percent of rainfall annually, and helps reduce peak flows and large volumes of rainfall (Hunt 2006). Care should be taken in selecting soil media to ensure that green roofs do not generate an export of nutrients in stormwater runoff.
- Mitigates heat island effect.
- Helps cleanse airborne toxins.
- Provides a carbon sink (Gilligan 2005).

5.5.3 Drainage and Impaired River Conditions

Depending on the level of implementation, green infrastructure can reduce drainage and flooding issues as well as high bacteria counts in rivers by reducing stormwater and CSO volume, and CSO events. Reducing these issues will protect public health by reducing the risk of flood hazards and getting sick when contacting the water in the rivers.

5.6 Summary of Triple Bottom Line Analysis

The above TBL analysis provides a compelling illustration of the magnitude and breadth of green infrastructure benefits in the pilot area given an extremely high level of implementation. Key findings from the analysis for the three sewersheds used in SUSTAIN include:

- Through job creation, an annual reduction of $220,000 in social costs, with a present worth of $2.7 million over 20 years.
- Through porous pavement and green alleys, 66 to 77 percent reduction in per unit storage costs.
- Through reduced pumping costs, a present worth savings of $46,000 over 20 years.
- Through improved aesthetics, a property value increase totaling $2.7 million.
- Through green alleys and bioretention areas, an 11-acre increase in recreation area.
- Through control and treatment of runoff, 435 acre-feet of reduced runoff per year, 68 US tons of reduced sediment loading per year, and 406 acre-feet of increased groundwater recharge per year.
- Through carbon sequestration, reduction of 156 tons of carbon dioxide over 20 years equivalent to annual carbon emissions from 2,652 automobiles and 1,318 single family homes.
- Through shade, reduction of 64,000 kWh in energy use and $3,900 to $5,700 in energy savings over 20 years.
- Additional benefits through improved quality of life, improved air quality, enhanced drainage, and protection of public health (reduced risk of getting sick when contacting the water in the rivers).

Considering that green infrastructure may represent part of the overall CSO volume reduction strategy, these practices would provide long-term economic, social, and environmental benefits beyond what grey infrastructure alone can provide. Numerous studies support these findings, and most notable among the findings is the reduction in social costs due to reduced poverty and the increases in property value. Some of the benefit estimates appear relatively small because the pilot area is small, and as green infrastructure is considered for a larger portion of the combined and separate sewer areas, the benefits will increase accordingly.

5.6.1 Extrapolation of Triple Bottom Line Benefits to the CSSA

To provide a rough estimate of the potential TBL benefits for the entire CSSA, the pilot area benefits determined for solution 2 were linearly extrapolated based on area. A factor of 25 was used to extrapolate the results, derived from the ratio of the entire CSSA area to the pilot area. The extrapolation assumes that land uses, soils, weather, average property values and the applicability of green infrastructure in the rest of the CSSA are identical to those in the pilot area. The extrapolation also assumes that hydrology and green infrastructure will behave in the same way within the entire CSSA.

The difference in land uses will affect the applicability of green infrastructure and serve as an indicator of the potential hydrologic response of the watershed. To help gage the applicability of the simple linear extrapolation, the distribution of land uses in the pilot area was compared to the distribution of land uses in the entire CSSA (see Table 5-3). The most significant difference is the proportion of industrial land use, which is 8 percent less in the CSSA than in the pilot area. This difference in land use will predominantly affect the regional bioretention, porous pavement, and green roof practice applicability by overestimating their applicability in the CSSA. The distribution of other land uses is between zero and four percent of the distribution of land uses in the pilot area. Available soils data suggest no significant difference between the pilot area and the rest of the CSSA. Weather data used in the pilot area analysis are assumed to be representative of the entire CSSA. A more detailed review of land use, aerial photography, and other data are needed to ensure that applicability is representative. However, this level of analysis is outside the scope of this project.

Table 5-3. Distribution of Land Uses in the Pilot Area and CSSA.

Land use group	Percent of pilot area	Percent of CSSA area	Difference CSSA - pilot area
Residential	35.9%	38.7%	2.7%
Commercial	5.5%	5.1%	-0.4%
Industrial	13.0%	5.0%	-8.0%
Transportation	40.4%	36.7%	-3.7%
Government and institutional	2.3%	5.6%	3.3%
Cemeteries	0.0%	0.6%	0.6%
Recreational	0.1%	3.3%	3.2%
Communications and utilities	1.0%	0.5%	-0.5%
Open natural areas	1.7%	4.3%	2.5%
Other (mixed commercial/residential)	0.0%	0.3%	0.3%
Total	100.0%	100.0%	

Using the linear extrapolation, the green infrastructure TBL benefits for the CSSA include:

- Through job creation, an annual reduction of $5.5 million in social costs, with a present worth of $68 million over 20 years.
- Through porous pavement and green alleys, 66 to 77 percent reduction in per unit storage costs.
- Through reduced pumping costs, a present worth savings of $1.2 million over 20 years.
- Through improved aesthetics, a property value increase totaling $68 million.
- Through green alleys and bioretention areas, a 275-acre increase in recreation area.
- Through control and treatment of runoff, 10,875 acre-feet of reduced runoff per year, 1,700 US tons of reduced sediment loading per year, and 10,150 acre-feet of increased groundwater recharge per year.
- Through carbon sequestration, reduction of 3,900 tons of carbon dioxide over 20 years equivalent to annual carbon emissions from 66,300 automobiles and 32,950 single family homes.
- Through shade, reduction of 1,800,000 kWh in energy use and $98,000 to $143,000 in energy savings over 20 years.

6 Lessons Learned, Recommendations, and Next Steps

The analyses presented in this report have confirmed the potential of green infrastructure to be an important component of improving environmental, economic, and social conditions within both the CSSA and the SSSA. A number of next steps should be considered to further identity the most cost effective means to move toward an increased level of green infrastructure implementation.

- The MACRO model is a simple, volumetric model used to simulate the overall response of the MMSD conveyance and treatment system to a wide range of hydrologic conditions. It is limited in its ability to simulate green infrastructure and there is some uncertainty as to the amount of imperviousness used in the model. Additional, more detailed modeling within the CSSA is therefore needed to obtain a better understanding of the potential for green infrastructure to reduce CSO volumes and events.
- A number of assumptions underlie the SUSTAIN model, many of which were made based on a desktop analysis of the pilot area. These assumptions should be verified through additional field work and analysis to strengthen the confidence in the model results.
- USEPA and Wisconsin Department of Natural Resources continue to evaluate methods by which to reduce sediment and nutrient loads to surface waters, including the development of new regulations and water quality standards. The cost effectiveness of treating sediment and nutrients using green infrastructure compared to treating these pollutants at wastewater treatment facilities could therefore be explored.
- A more thorough comparison of the cost of using grey infrastructure compared to green infrastructure can now be made given the SUSTAIN modeling results. For example, a potential opportunity to separate the sewers along Capitol Drive from 20th Street to the Milwaukee River has been identified. The cost to separate the sewers could be computed and compared to the cost of implementing green infrastructure to accomplish a comparable level of water quality improvement and combined sewer volume reduction.
- The current SUSTAIN modeling results are based on capital costs only and do not include operation and maintenance costs. SUSTAIN could be re-run to include operation and maintenance costs. This would allow a more thorough cost-benefit analysis.
- A detailed extrapolation of the TBL benefits could be made to the entire CSSA or SSSA through additional research and GIS analysis.
- Moving from a grey to a green and grey infrastructure system will require extensive community support and strong partnerships. To build this support, it will be important to effectively communicate the benefits of green infrastructure through a demonstration of its sound science and engineering, cost effectiveness, socioeconomics as well as environmental appeal.

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