GIST – the Green Infrastructure Model for the Kinnickinnic River Watershed

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Background

Context

Budgets for adaptation and resilience are limited. Competing priorities – social justice goals, economic development goals, health goals, water and air quality goals, greenhouse gas reduction goals – demand attention even while communities try to adapt to unavoidable climate impacts. In Milwaukee, Wisconsin an innovative partnership is helping people discover for themselves the opportunities where, far from competing with each other, all of these important values rise as one.

The inspiration for the work is the increase in flooding events in Milwaukee and the expectation that, with climate change, there will be a further increase in extreme precipitation events. But the project goes far beyond the single dimension of stormwater management by helping the community identify the actions and investments that build readiness for more intense storms AND improve the everyday livability of the community.

Our partnership is an unusual one, transcending typical boundaries of geography and discipline. The primary partners include a climate change think tank, Climate Interactive, a regional wastewater authority, the Milwaukee Metropolitan Sewerage District, and a neighborhood health center, the Sixteenth Street Community Health Centers. Beyond this partnership we have involved municipal leaders, environmental organizations, the local university, business groups, and neighborhood groups in shaping and guiding our work.

The Green Infrastructure Decision Support tool is the result. The tool is a computer simulation that focuses on a twenty-six square mile watershed within the greater Milwaukee region. We are engaging the community using the tool and inviting them to work to steer the investment of an estimated $150 million that will be spent on water infrastructure projects in the watershed in the next five years towards those projects that bring the biggest benefit to the communities of the watershed.

The simulation allows users to test investments into different types of infrastructure for managing stormwater. Users can build more grey infrastructure or invest in new green infrastructure such as green roofs, pervious pavement, and rain gardens. The simulation reports a full picture of the implications of each investment. It shows what people expect to see: upfront and ongoing costs and information on flooding and the number and volume of sewer overflows. But the simulation goes further, showing the non-stormwater benefits to the community for each investment scenario including jobs, green space, water quality, air quality, property values, energy savings, and the urban heat island effect.

Purpose and intended use

The Green Infrastructure decision Support Tool (GIST) is a simulation that helps users explore the consequences of investment choices in green or grey infrastructure for the Kinnickinnic River Watershed of the greater Milwaukee, Wisconsin area. The simulation is intended for interactive scenario exploration. It helps people to think about:

- The multiple benefits of green infrastructure beyond stormwater management
- How infrastructure might perform under different climate conditions
- The costs and benefits for green vs. grey infrastructure investment choices
- The dynamics over time of investment in new infrastructure
- The roles residents, business owners, and municipal officials all can play in bringing green infrastructure to scale.

While the simulation is for a specific region, it's generalizable lessons about risk and uncertainty, multiple benefits, synergies and trade-offs are relevant to decision makers grappling with responding to climate change in the midst of economic, development and other challenges.

Audience

GIST is primarily designed for people with an interest in infrastructure decisions in their community – business owners, residents and neighborhood association leaders, environmental groups, and municipal and state officials. It aims to ground conversations between these groups in the best available data and science while not distracting from important conversations about goals, values, priorities and strategies with an overly technical interface or information of too much detail.

Underlying philosophy

In creating the simulation we had four important assumptions:

People need tools to see what they could accomplish together with Green Infrastructure

Facing unavoidable climate change, communities need to be able to ask 'what if' questions about the performance of today's infrastructure under different climate conditions.

Those most impacted by infrastructure decisions need to have a say in those decision.

People need ways to explore which suite of green infrastructure approaches offers the benefits that they prioritize for their community.

Simulation tools don't provide answers, but do provide grounding and rigor for more effective conversations.

Model structure overview

Simulation method

The GIST simulations run from the present out to 10 years into the future (although the tool can also be used in a 20 year mode). Model values are updated each day (Δt) and reported in the same interval. The very short Δt is necessary to account for the short duration events (rain storms) and the long run time is needed to reflect the slowly changing nature of infrastructure, including staging of development.

The model is an ordinary differential equation system, solved by Euler integration.

Scope & detail

The model represents the movement of water falling as precipitation onto the various surfaces of the watershed (the make up of which can change over time) and being captured and transported by both grey and green infrastructure. The amount of green and grey infrastructure is determined by the user who invests in grey, green or a combination of both types of infrastructure.

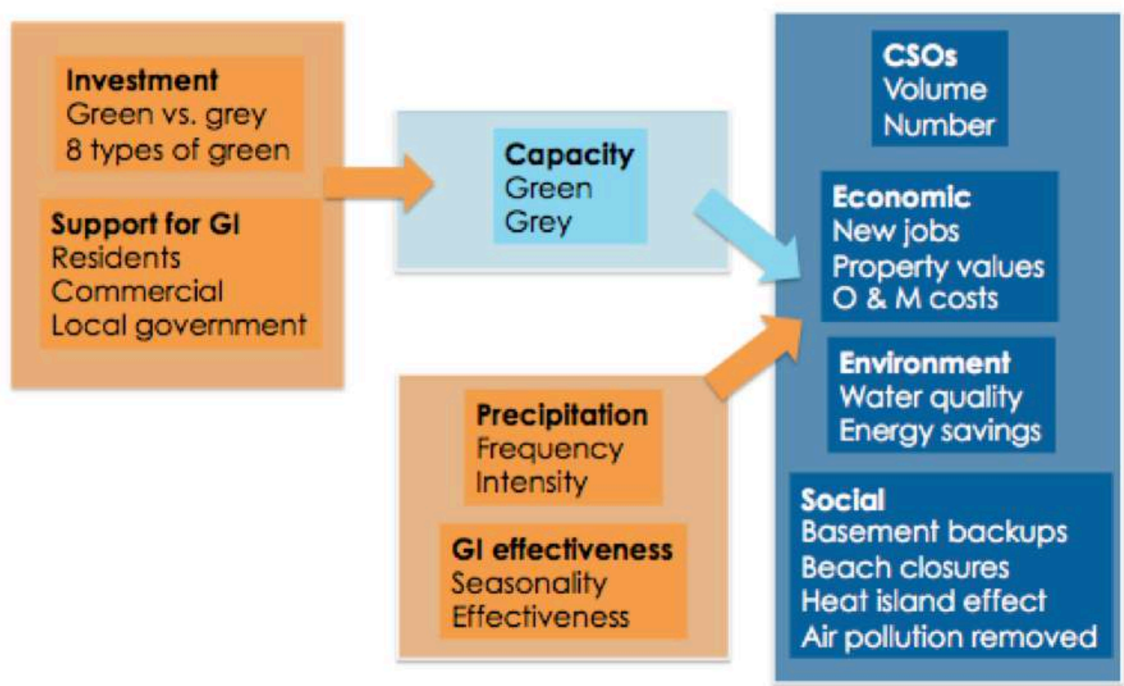
Pollutant loadings are also tracked as the water comes in contact with green infrastructure or water treatment infrastructure both of which can remove pollutants.

Investment decisions trigger the construction of new infrastructure, which creates additional jobs that are tracked and reported over time.

The simulation tracks additional benefits of GI including energy savings from green roofs, increased property value, air quality benefits, and reduction in the urban heat island effect.

In order to preserve simplicity and provide rapid simulations, the model is spatially homogenous. Other tools are more suitable for informing decisions about where to build or add GI. GIST is most helpful in helping a community to explore the extent to which GI can help achieve a portfolio of desired goals.

The following diagram shows the overall simulation structure.

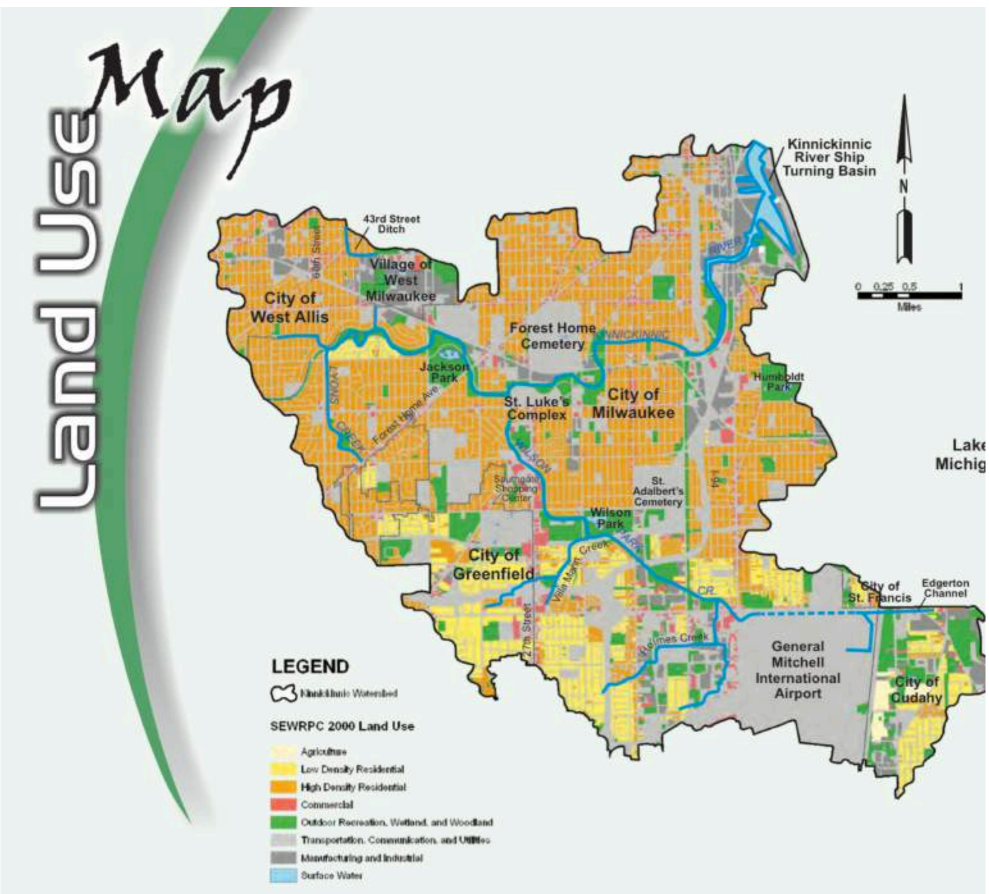


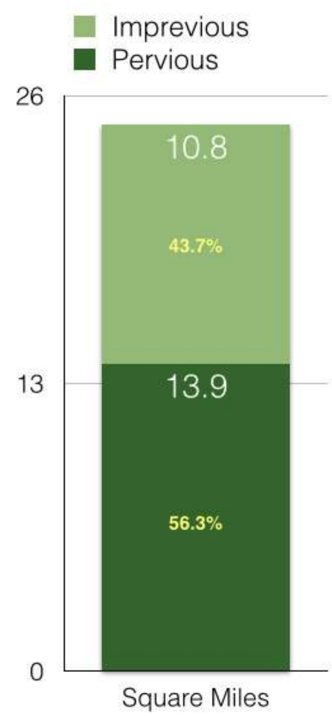
Representation of the watershed

The Kinnickinnic River Watershed

The Kinnickinnic River Watershed is a region of 24.7 square miles and includes sections of the following cities: Milwaukee, West Allis, Greenfield, St. Francis, Cudahy, and West Milwaukee. 145,000 people live in the watershed, the most densely populated watershed in the region. 81% of the population resides in the City of Milwaukee.

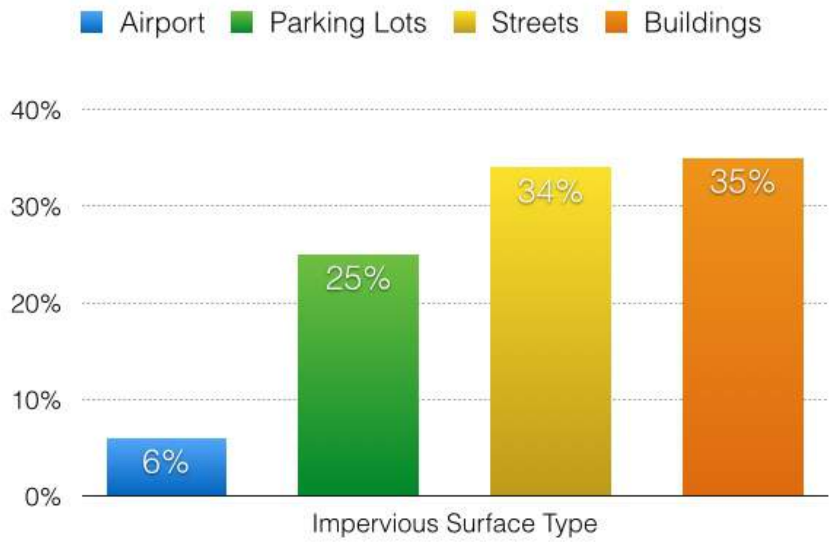
The land use of the watershed is shown in the following map, from the Milwaukee Metropolitan Sewerage District (MMSD State of the Watershed 2013):





GIST distinguishes between the watershed's pervious and impervious surface areas in the model. The chart shows these two surface areas for the Kinnickinnic watershed, breaking down the 24.7 sq. miles according to the following percentages: 43.7% impervious, 56.3% pervious.

The type of impervious surface area is shown in the chart below. These categories aggregated into the 10.8 square miles in the top portion of the bar chart above. (MMSD 2013a)



Sewer system

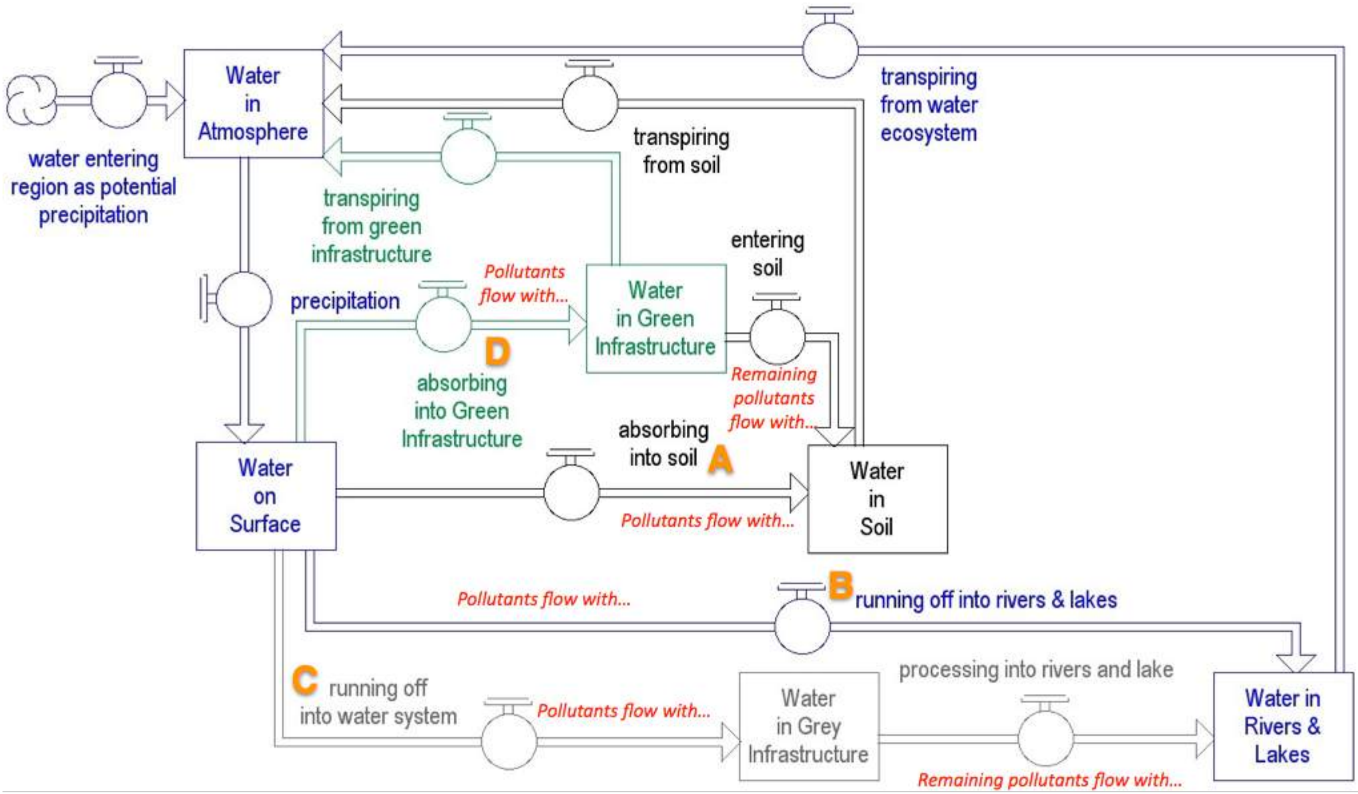
Separated and combined sewers are represented as distinct entities in the simulation. The Kinnickinnic River watershed contains a mix of separated sewer areas and combined sewer overflow areas. The combined sewer area makes up roughly 16% percent of the area of the watershed.

Soil absorption capacity

The model currently assumes that soil can hold up to .25 gallon per square foot.

Water flows

The model uses a stock flow "water cycle" structure to simulate where water accumulates and flows in the KK region. In the diagram, water may enter the region as potential precipitation. When precipitation occurs, it accumulates on the surface. It may either be absorbed by the soil (A), run off into rivers and lakes (B), or enter the grey infrastructure (C). If green infrastructure is developed, water may also accumulate there (D). Water will eventually flow into rivers and lakes and back into the atmosphere. As water flows through the region, it will carry pollutants with it. The grey and green infrastructure may remove pollutants, and the remaining pollutants travel with the water as it continues to flow.



Investment and construction

Users control the amount and timing of investment in green and grey infrastructure – allocating investment between the eight types of green infrastructure (see Green Infrastructure section for a description of the types) and in any of four different types of municipal or regional grey infrastructure.

Grey infrastructure requires only the investment decision to spur a wave of construction, but green infrastructure requires both funding and 'support' from three constituencies:

- Residential
- Business/Commercial
- Local Government

Full investment requires the full support of each group. The different groups have different levels of impact on the decision to install each type of infrastructure. The default percentages of influence are shown below. The user also has the opportunity to change these percentages.

	Green Roofs	Porous Pavement	Bioretention	Native Landscaping	Rain Barrels	Cisterns	Soil Amend ments	Storm water Trees
Residential	0	20	60	40	70	20	40	20
Commercial/Ind ustrial	90	40	20	20	10	70	20	10
Local Government	10	40	20	40	20	10	40	70

Infrastructure

Representation of grey infrastructure

In the simulation grey infrastructure can either be municipal (any one of the 6 municipalities) or regional (MMSD). Grey infrastructure is further divided into:

- Storm sewers
- Sanitary sewers
- Combined sewers
- Processing

Anecdotal evidence from the MMSD suggests that the limiting aspect of grey infrastructure when it comes to CSO events lies upstream in municipal combined sewers rather than in the MMSD system. GIST reflects this feature of the system in that investments in municipal grey infrastructure are more effective than investments in MMSD grey infrastructure.

The initial capacity of grey infrastructure in the simulation was determined in consultation with the MMSD, who further reached out to municipalities for estimates of the grey infrastructure capacity in each city. The initial capacities are set as follows:

	Initial Volume MG
Sanitary Sewers	5.8
Combined Sewers	62.1
Storm Sewers	20.2
Conveyance	39
Storage	118
Processing Capacity	87

Costs

Adding additional Green Infrastructure comes with costs estimated per unit based on records from the MMSD for recent construction projects as follows:

	Cost per additional MG volume
Sanitary Sewers	$2,400,000
Combined Sewers	$2,400,000
Storm Sewers	$2,400,000
Conveyance	$2,400,000
Storage	$2,400,000
Processing Capacity	$1,833,333

Each unit of green infrastructure also has annual operating costs, which we also determined from the MMSD's records.

	Annual O&M per MG volume
Sanitary Sewers	$115,385
Combined Sewers	$115,385
Storm Sewers	$115,385
Conveyance	$115,385
Storage	$38,136
Processing Capacity	$103,448

Performance

The model currently uses the following chart to estimate storage volume and overflow volume (aka Deep Tunnel) for Kinnickinnic watershed.

CRITERIA	ENTIRE MMSD SERVICE AREA	KINNICKINNIC RIVER WATERSHED	UNITS
Base sanitary flow	128.86	24.68	Million Gallons per Day
Total peak **instantaneous** 5-year wastewater recurrence interval flow generated in the combined sewer area	20,590	3,463	Flow rate in Million Gallons per Day
Total peak hourly flow from the separate sewer area	1,293	183	Flow rate in Million Gallons per Day
% of the total flow from the KK River	100%	17%	
Total flows at the wastewater plants	620	103	Million Gallons per Day
Total Storage Volume	521	87	Million Gallons

Total Overflow Volume	710	118	Million Gallons
Total Volume of MMSD Conveyance System	237	39	Million Gallons
Volume in municipal system		88	Million Gallons
Sanitary sewers		5.8	Million Gallons
Combined sewers		20.2	Million Gallons
Storm sewers		62.1	Million Gallons
5-year, 24-hour precipitation	3.14	3.14	Inches
Volume of rain associated with a 5-year rain in the KK Watershed	22,447	1,345	Million Gallons

Green

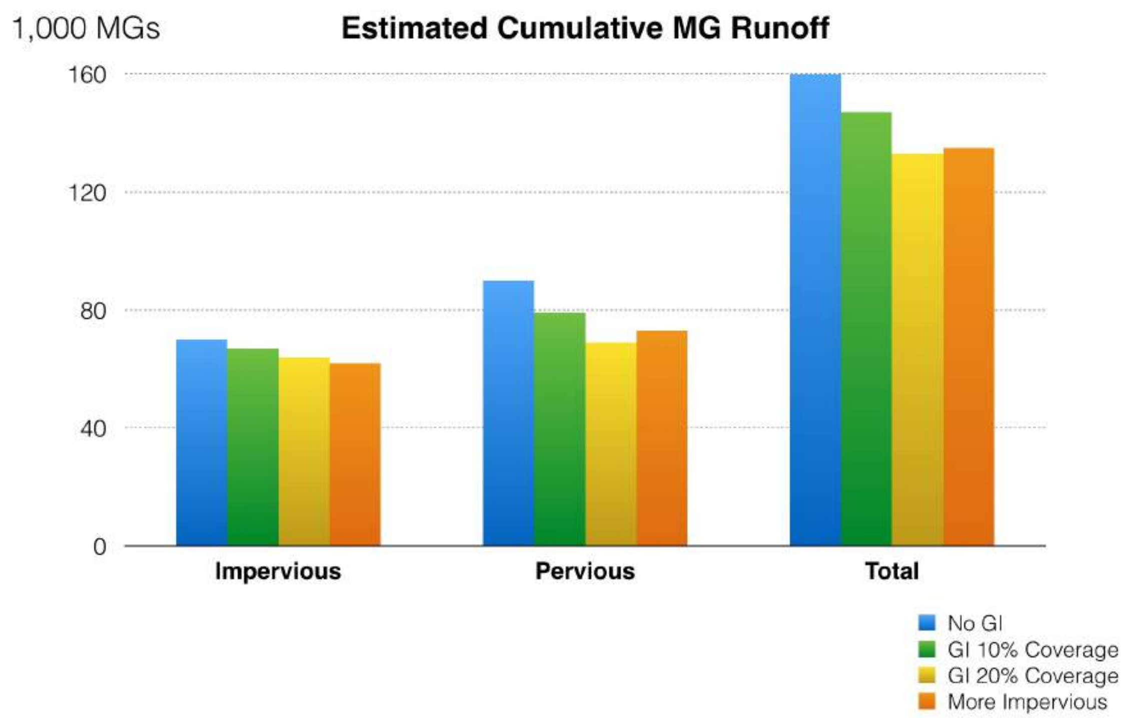
Types

There are eight types of green infrastructure in the simulation.

- Green roofs
- Bioretention
- Stormwater trees
- Native landscaping
- Porous pavement
- Rain barrels
- Cisterns
- Soil amendments

Below is a chart comparing estimated runoff across the KK under three scenarios (for 11 years of historical precipitation data):

- No green infrastructure
- 10% area covered with green infrastructure
- 20% area covered with green infrastructure (similar to MMSD plan)
- Similar size (in millions of dollars) investment to the 20% coverage scenario, but with more porous pavement and green roof investment, less pervious investment



Costs

The model currently assumes installation costs as they appear in the following table, derived from the MMSD's regional green infrastructure plan.

	Estimated $ per sq. ft. or unit installed
Green Roof	$11.50
Bioretention	$17.00
Stormwater trees	$251.20
Native landscaping	$0.11
Porous pavement	$10.00
Rain barrels	$120.00
Cisterns	$5,000.00
Soil amendments	$0.07

MMSD 2013a

The following table contains estimated operating costs for different forms of Green Infrastructure.

	Annual O&M cost per sq. ft. or unit	Annual O&M cost per sq. ft. or unit (Comparable)
Green Roof	$8,712	$3,920
Bioretention*	$9,148	$3,916
Stormwater trees	$1,387	$245
Native landscaping	$120	$920
Porous pavement*	$4,356	$2,904
Rain barrels	$3	$-
Cisterns	$100	$-
Soil amendments	$900	$1,000

MMSD 2013a

Based on the MMSD plan, the model uses the following investment costs and units.

	Estimated KK Sq. Ft or Units	Total MMSD Plan Cost ($M)
Green Roof	4,992,646	$57
Bioretention	3,300,000	$56
Stormwater trees	1,000	$1
Native landscaping	44,072,471	$5
Porous pavement	6,089,519	$61
Rain barrels	17,100	$2
Cisterns	200	$1
Soil amendments	45,662,897	$1

Performance

The following table contains estimated performance for different forms of Green Infrastructure.

GREEN ENERGY INFRA-STRUCTURE	UNITS	POTENTIAL PHYSICAL STORAGE CAPACITY			ANNUAL RUNOFF CAPTURE PERFORMANCE		
		PHYSICAL STORAGE CAPACITY ASSUMP-TIONS	POTENTIAL STORAGE CAPACITY (GALLON)	EXPECTED IMPERV-IOUS AREA MANAGED PER UNIT (SF)	EQUIVALENT CAPACITY (INCHES FROM CONTRIBUTING AREA)	AVERAGE ANNUAL PERCENT CAPTURE	ESTIMATED AVERAGE CAPTURE (GALLON/ UNIT)
Green Roofs	SF	5-inch growth media with 34% voids	1.1	1	1.7	97	18
Bioretention / Bioswales / Greenways	SF	6-inch surface storage, 24-inch soil	7.5	12	1	90	199
Stormwater Trees	Each	0.26-inch perception, 50% of 10-foot radius canopy	25	157	0.26	52	1,493
Native Landscaping	SF	Curve number reduced from 86 to 71	0.4	N/A	0.58	77	2.5
Porous Pavement	SF	12-inch gravel bed with 40% voids	3	4	1.2	93	69
Rain Barrels	Each	Empty 55-gallon MMSD rain barrel	55	350	0.25	50	3,256
Cisterns	Each	Empty 1,000-gallon cistern	1,000	6,500	0.25	50	60,465

Soil Amendments	SF	Curve number reduced from 84 to 74	0.2	N/A	0.39	64	2.1
Rain Gardens	SF	4-inch surface storage, 12-inch soil	4.4	12	0.58	77	170

MMSD 2013b

Pollutant Removal

Values for the removal efficiency for different types of Green Infrastructure were provided by Fitzgerald Environmental Associates based on a literature review. The sources are listed in the table. The model uses averages from across these studies.

Table 8. Literature review of pollutant removal percentages based on BMP type: bolded values were selected for this study.

BMP	TSS	TP	TN	Bacteria	Source	Notes
Wet Basin	80	51	33	70	VT Stormwater Management Manual (2001)	
	80	52	45	70	National Pollutant Removal Performance Database – CWP (2007)	
	75	18		--	UNH Stormwater Center Report (2009)	
	80	50	30	70	Urban Subwatershed Restoration Manual 3 – CWP (2007)	
	80	**50**	**35**	--	NYDES – NYS Stormwater Management Design Manual, Appendix A (2001)	
	95	**60**	**90**	--	Farrell Street Wet Pond Performance Report (VHB, 2011)	
Dry Basin	49	20	24	88	National Pollutant Removal Performance Database – CWP (2007)	
	88	58		--	MNDOT: Water Quality Performance of Dry Detention Ponds with Under-Drains (2006)	12 storms at 1 DD basin in MN, relatively low inflow concentrations.
	61	19	31	--	NPDES Dry Detention Pond Factsheet (2006)	
	50	**20**	**25**	**--**	**FEA Composite Removal Efficiency Estimate**	
Wetland	76	49	30	78	VT Stormwater Management Manual (2001)	
	72	48	67	78	National Pollutant Removal Performance Database – CWP (2007)	
	90+	40		--	UNH Stormwater Center Report (2009)	
	70	50	25	60	Urban Subwatershed Restoration Manual 3 – CWP (2007)	
	80	50	30	--	NYDES – NYS Stormwater Management Design Manual, Appendix A (2001)	

BMP	TSS	TP	TN	Bacteria	Source	Notes
	95	**85**	**75**	--	CSB Farrell Park Gravel Wetland Performance Report (2012)	
Bio-basin	59	5	43	37	National Pollutant Removal Performance Database – CWP 2007	
	100	8		--	UNH Stormwater Center Report (2009)	
	60	**5**	**45**	50	Urban Subwatershed Restoration Manual 3 – CWP (2007)	
Porous Asphalt - Infiltration	95	80	51	--	VT Stormwater Management Manual (2001)	
	89	65	42	--	National Pollutant Removal Performance Database – CWP 2007	
	90	**70**	**50**	--	NYDES – NYS Stormwater Management Design Manual, Appendix A (2001)	
Swirl	60-80			--	Assessment of Hydrodynamic Separators for Stormwater Treatment – Journal of Hydraulic Engineering (2009)	TSS removal highly variable based on inflow particle size and velocity
		15	15	--	Fairfax County LID BMP Factsheet Hydrodynamic Separators (2005)	
	60	**15**	**15**	**--**	**FEA Composite Removal Efficiency Estimate**	Varies based on manufacturer and model.
Storage Tanks	**20**	**5**	**5**	**--**	**FEA Removal Efficiency Estimate**	

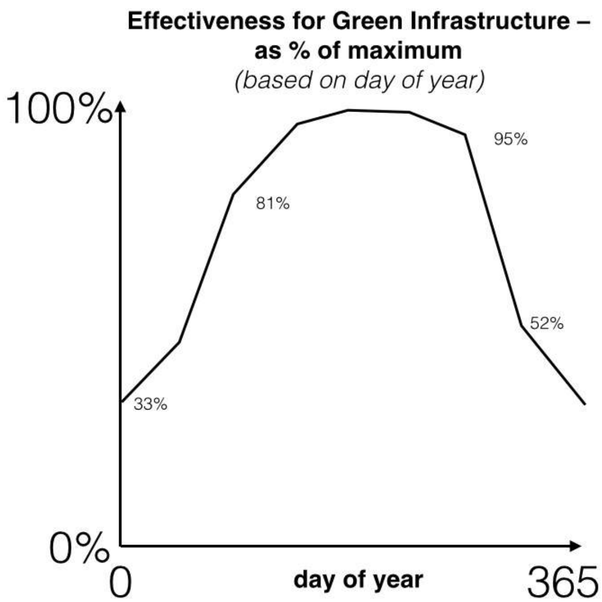
Seasonal Effectiveness

Green infrastructure may not be as effective in the winter months in colder climates. To allow for this potential in the simulation the user can make GI less effective during different months of the year. This feature is switched off in the base runs of GIST but can be turned on if desired.

When the seasonal effectiveness switch is 'on' the default impact on GI effectiveness is shown in the following graph, although the user can also change the effectiveness graph. We set the shape of the seasonal effectiveness curve based on this study:

"In summer, depending on the plants and depth of growing medium, green roofs retain 70-90% of the precipitation that falls on them; in winter they retain between 25-40%. For example, a grass roof with a 4-20 cm (1.6 - 7.9 inches) layer of growing medium can hold 10-15 cm (3.9 - 5.9 inches) of water." Source: Green Roofs for Healthy Cities. Green Roof Benefits. Accessed 12/9/14. http://www.greenroofs.org/index.php/about/greenroofbenefits

The model uses a graphical relationship to estimate expected effectiveness for green infrastructure based on the day of the year. The assumption is that in summer, green infrastructure can achieve maximum effectiveness (100%) but that other times of the year it might achieve less. The graphical relationship is shown here.



Stormwater management

CSO events

The simulation generates CSO events when the volume of water in the combined sewer system exceeds the storage and flow capacity of the system. The simulation tracks these events and reports both the volume and number of CSO events.

Comparison to historical behavior

One confidence-building test of GIST was to run the simulation using historical precipitation and comparing the simulated volume and timing of CSO events with the historical record. The following chart shows that, when driven by historical precipitation the simulation produces a pattern of behavior very similar to the historical pattern.

Chart #1 – CSO volumes over time. Black = historical; Blue = Simulated.

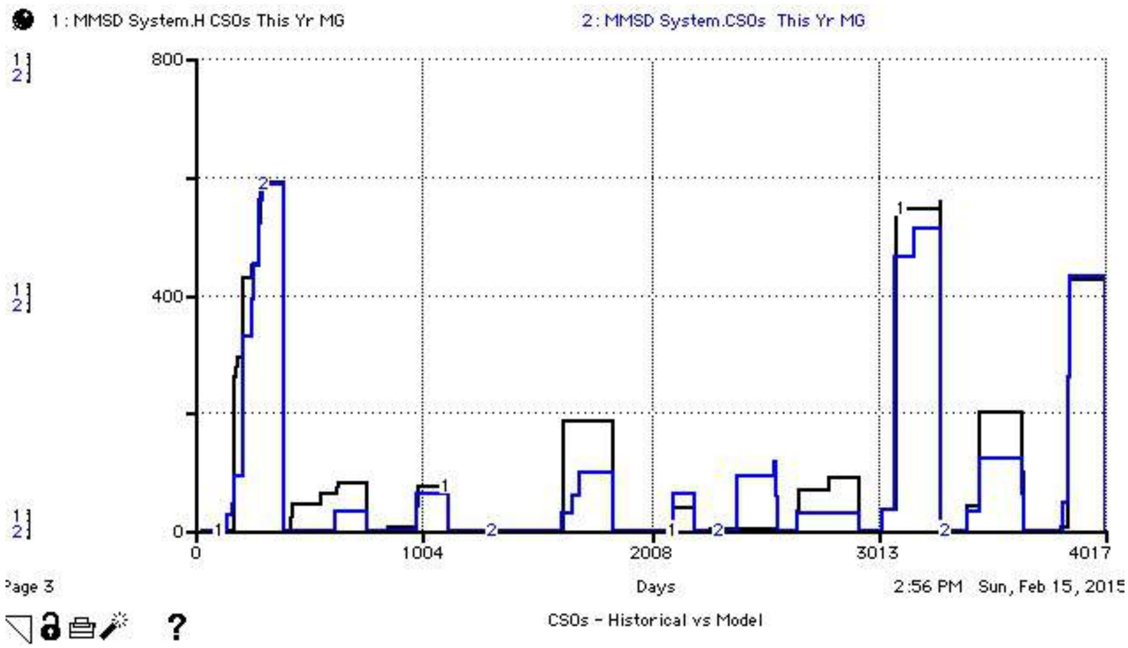


Chart #2 – Cumulative CSO events. Black = historical; Blue = Simulated.

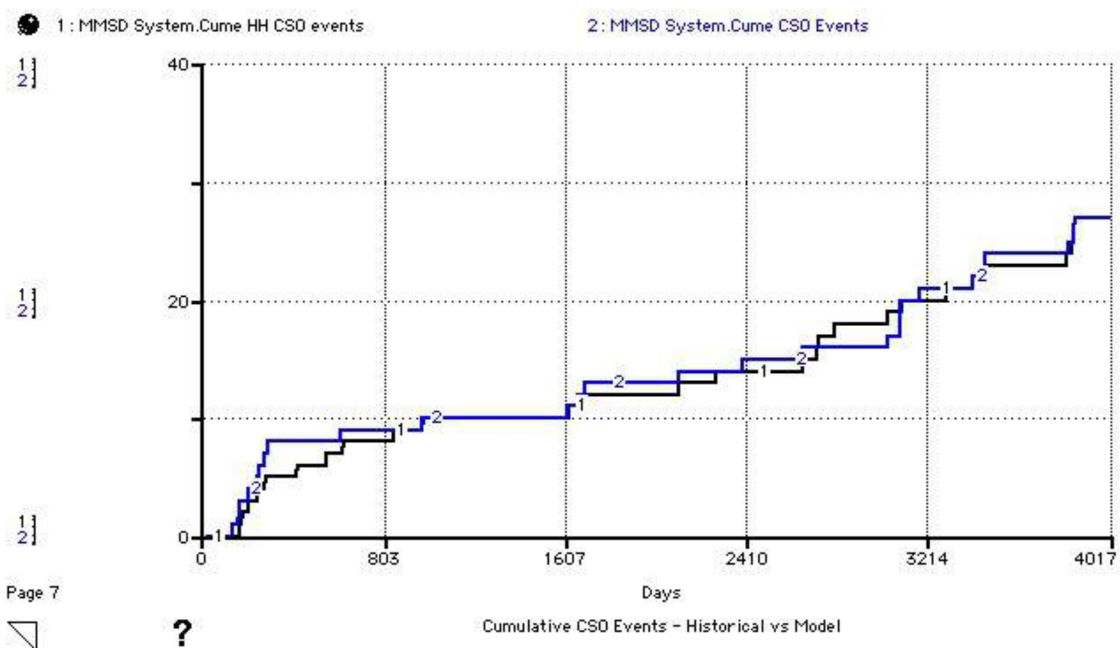
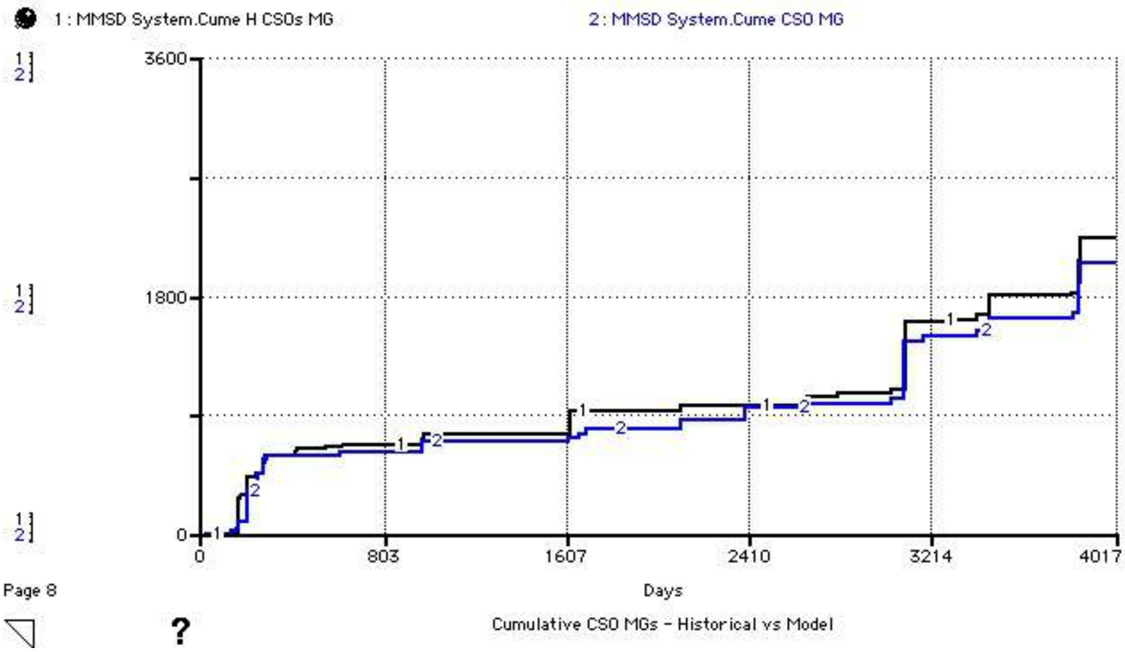


Chart #3 – Cumulative CSO volume. Black = historical; Blue = Simulated.



Basement backups

The model currently assumes Combined Sewer Overflows are a good predictor of Basement Back Ups. Only CSOs above 150 are assumed to generate basement back-ups. We plotted the relationship between historical CSOs and historical basement backups as follows:

The data used to fit the equation is:

	CSOs	BBUs	Exp BBUs
6/14/08	510	6969	11747
6/20/09	159	1565	6210
7/22/10	337	18424	9024

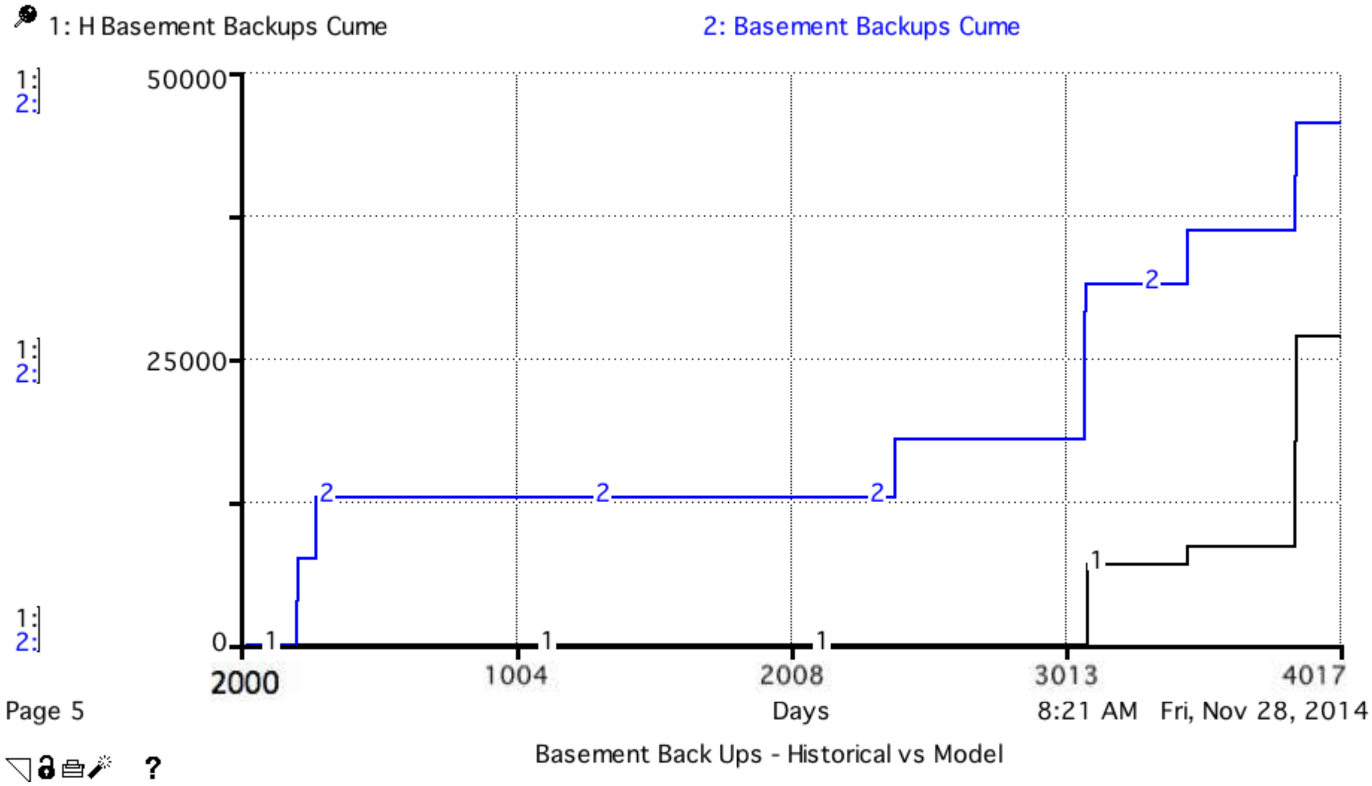
Result: $y = 15.77797678\ x + 3695.118454$

Correlation Coeficient: $r = 3.216706905 \cdot 10^{-1}$

Residual Sum of Squares: rss = 132879227.9

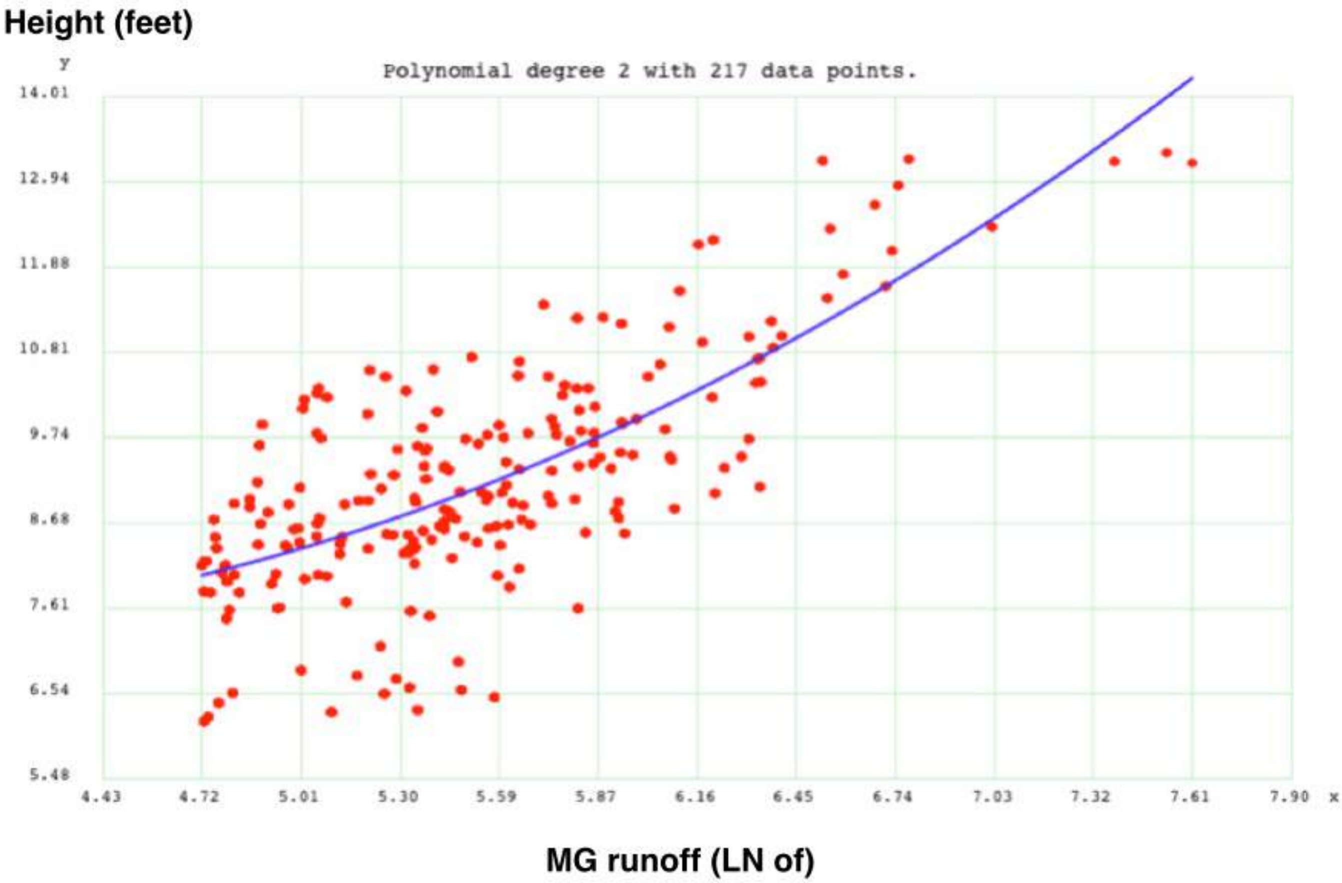
Comparison to historical behavior

We compared historical basement back-ups to basement back-ups simulated by GIST when driven by historical precipitation. The results do not closely replicate history, but this is expected given that often backups aren't reported by homeowners.



Out of bank flooding

The model uses rainfall (gallons per sq. ft.) to calculate potential water levels and out of bank flooding events. Current model uses the following nonlinear regression: fit LN of remaining MGs in region (from model) versus historical water height.



Mode: normal x,y analysis
Polynomial degree 2, 217 x,y data pairs.
Correlation coefficient (r^2) = 0.5442602110156094
Standard error = 0.9644994437787298
Coefficient output form: mathematical function:

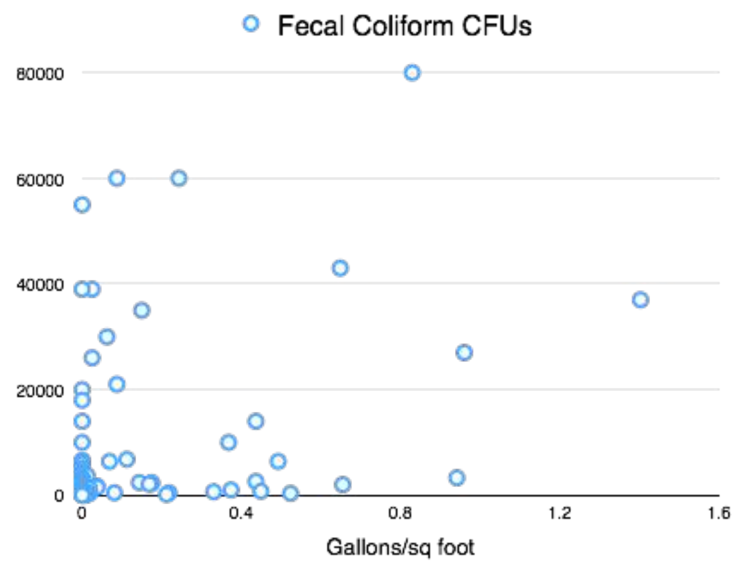
f(x) = 1.1533615765950225e+001 * x^0
+ -2.5405437108849434e+000 * x^1
+ 3.8045489157009910e-001 * x^2

The initial condition that triggers a high water event (in the model) is a reading of 12' or greater.

Water quality

Reasoning behind approach to water quality modeling

When it comes to water quality, many conditions in the watershed are exogenous to the simulation, including any variations in loadings coming off of the surfaces of the watershed. A chart of the historical readings for Fecal Coliform (CFUs) relative to historical precipitation (gallons/sq. foot) is shown here. The readings for CFUs are from monitoring data at measurement station RI-13S, located near S. 11th St. There is little statistical relationship to predict loadings based on precipitation.



From data like this, we concluded that there are more variables than precipitation amount influencing the runoff of pollutants into the Kinnickinnic River watershed, implying that factors outside the boundaries of GIST come into play. Therefore we sought a simpler way to show the potential impacts of GI investment on water quality – estimating how much the efficiency of GI at removing pollutants from runoff and deducting that amount from estimates of the pollutants picked up as water passes over the various surfaces of the watershed.

Water quality modeling

GIST tracks three types of water pollutants: Phosphorous, Total Suspended Solids, and Fecal Coliform colony forming units.

As precipitation hits the surface of the watershed it picks up pollutants with rates that depend on the type of surface (previous or impervious). GIST's assumptions about these loadings are based on the following table developed by research from Fitzgerald & Associates:

	mg/L	mg/L	colonies/ 100ml
Surface	**P**	**TSS**	**CFU**
Roads	0.44	157	22000
Parking lots	0.2	100	18000
Buildings	0.13	14	5000
Impervious other	0.56	173	17000
Open space	0.21	83	50700

Woodland	0.12	78	3000

GIST aggregates surfaces into two types: Pervious and Impervious. The model uses the fraction of surface areas (fraction of impervious and fraction of pervious shown in the first table below) to calculate a weighted average for each detailed surface type (second table below). The resulting two tables are:

	Fraction
AIRPORT	0.060
BUILDING	0.350
PARKING LOTS	0.250
STREETS	0.340
TOTAL IMPERVIOUS	1.000
Public lg turf	0.167
Priv lg turf	0.200
Res yards	0.633
TOTAL PERVIOUS	1.000

Surface	**P (mg/L)**	**TSS (mg/L)**	**CFU (colony forming units)**
Streets	0.150	53.380	7480
Airport/pkg	0.062	31.000	5580
Bldgs	0.046	4.900	1750
IMPERV	0.257	89.280	14810
Lg turf	0.044	28.600	1100
Open space	0.133	52.567	32110
PERV	0.177	81.167	33210

In GIST, pollutants are removed as water passes through either wastewater treatment processing or green infrastructure. The following table shows GIST's assumptions about the efficiency of removal of pollutants for both water treatment and the various types of green infrastructure in the simulation.

The default GIST removal efficiency for water processed through the treatment facility is 100% for all types of pollutant. This can be modified.

The removal efficiency of each type of Green Infrastructure was determined by research provided by Fitzgerald & Associates. The detailed research is in the appendix. The summary is provided below.

REMOVAL % BY GI TYPE	P	TSS	CFU
Wet basin	50	80	50
Dry basin	20	50	20
Wetland	85	95	85
Bio basin	5	60	10
porous	70	90	50
swirl	15	60	50
tanks	5	20	10

Health and Quality of Life

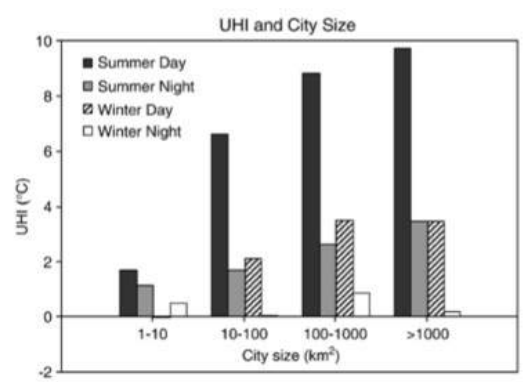
Air pollution

The simulation calculations the cumulative millions of pounds of particle pollution (PM10) removed by the vegetative mater of the installed green infrastructure. The assumptions we used about pollutant removal per unit of different types of green infrastructure are listed in the table below.

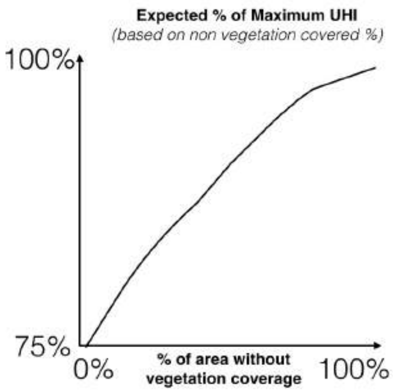
	Pounds per unit per year
Green Roof	9.2
Bioretention	21
Stormwater trees	0.2
Native landscaping	21
Porous pavement	0
Rain barrels	0
Cisterns	0
Soil amendments	9.2

Urban heat island

Urban heat island (UHI) is the difference in temperature between the center of a metropolitan region and the surrounding non-urban regions. Milwaukee is assumed to have a summer day UHI of approximately 9° C. This is from an estimated surface area of between 100-1000km2 (in the table from Imhoff et al). This is assumed to maximize at 9° in the summer months and reduce to about 3° in the winter.

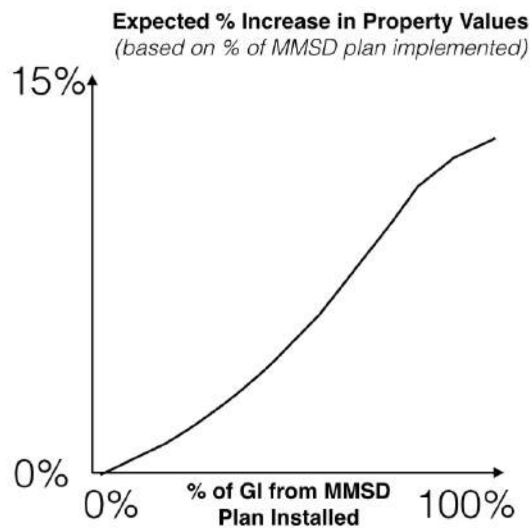


As the % of impervious only (not vegetation covered) surfaces decreases, there is a % reduction in the UHI. The corresponding reduction chart is shown here.



Property values

In GIST increase in green space results in an increase in property values. The effect is based on research from the Center for Neighborhood Technology, whose research is described in detail below.



The relationship between increase in green space and increase in property values in GIST is shown in the chart. This is the cumulative % increase that would occur if all of the Green Infrastructure proposed in the MMSD plan was implemented. Each type of Green Infrastructure has a different curve (less than the one shown) that when added up generates the curve shown. The current maximum is a 13% increase.

"Several empirical studies have shown that property values increase when an urban neighborhood has trees and other greenery. For example, one study reported an increase in property value of 2–10 percent for properties with new street tree plantings in front (Wachter 2004; Wachter and Wong 2008). Another study done in Portland, Oregon, found that street trees add $8,870 to sale prices of residential properties and reduce time on market by 1.7 days (Donovan and Butry 2009). An extensive study on the benefits of green infrastructure in Philadelphia also explores the effect that these practices have on property values (Stratus 2009). While the authors conclude that property values are notably higher in areas with LID and proximity to trees and other vegetation, they also note the difficulty in isolating the effect of improved aesthetics and avoiding double-counting of benefits such as air quality, water quality, energy usage (often relating to heat stress) and flood control that also impact property values. In this study, a range of 0– 7 percent is presented as suggested in literature, and a mean increase of 3.5 percent is chosen (Status 2009). Ward et al. (2008) estimate property values in the range of 3.5–5.0 percent higher for LID adjacent properties in King County, Washington." Source: Center for Neighborhood Technology. The Value of Green Infrastructure. pg. 48. 2010. http://www.cnt.org/media/CNT_Value-of-Green-Infrastructure.pdf

Economic impacts

Jobs - Grey and Green

Green

The model currently assumes that the following hours are required for installation of GI. These hours are for contractors *and* grantees. They currently exclude volunteer hours.

GI Type	$	SF	$/SF	Hours	Hours/SF
Green Roof	$2,065,989	91,061	$22.69	7032	0.08
Porous Pavement	$161,068	49,900	$3.23	507	0.01
Cisterns	$275,416	3,500	$78.69	258	0.07
Bioswales	$75,000	11,651	$6.44	825	0.07
Native Landscapes	$131,155	42,200	$3.11	65	0.00

The analysis was provided by MMSD. Excel Source file: GI Analysis tab in MMSD Draft Jobs Analysis Updated.XLSX

Grey

The model currently assumes that the following hours are required for installation of grey infrastructure.

Total	FTE count	FTE per Million
$44,463,914	122.1	2.7

The analysis was provided by MMSD. Excel Source file: Capital Projects Analysis tab in MMSD Draft Jobs Analysis Updated.XLSX

Currently 2.7 FTE/$1M spent.

Energy savings

The GIST model calculates energy savings from reduced heating and cooling from green roofs and from savings (particularly in cooling) from stormwater trees. The amount of energy savings per unit of these two types of GI is shown below.

	$ saved/sq ft (or unit)
Green Roof	$0.024
Stormwater trees	$13.00

Rainfall Scenarios

Default assumptions

Historical precipitation records were used to set general parameters for frequency and magnitude of precipitation events. Historical data were measured daily (2000-2010) at Milwaukee Mitchell Airport by NOAA. We used statistical analysis to set the parameters for the baseline precipitation as follows.

Poisson (to generate occurrence)

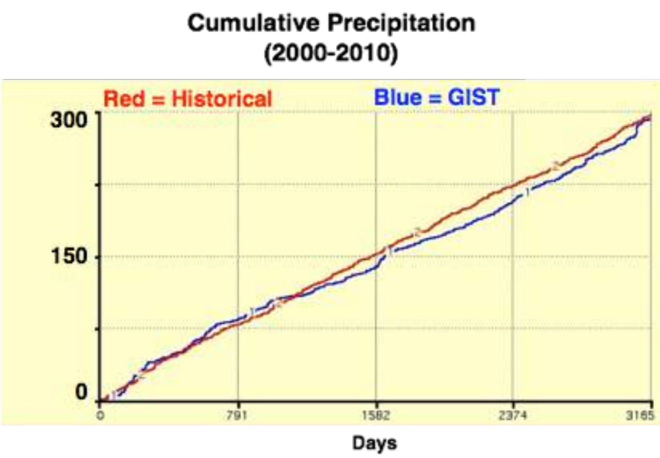
mean=.415

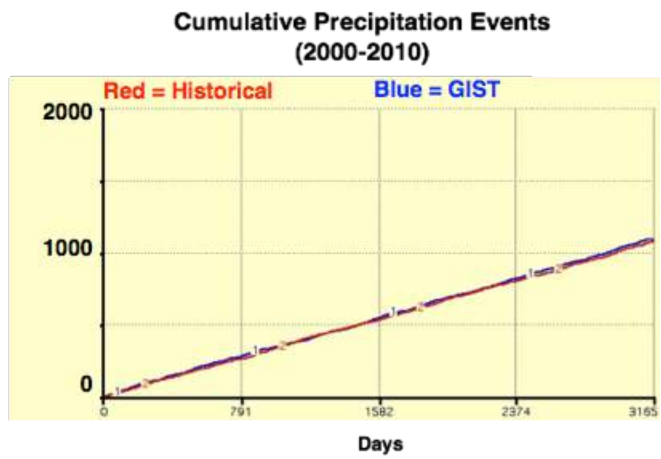
Weibull (to generate volume)

scale=6.3

shape=.82

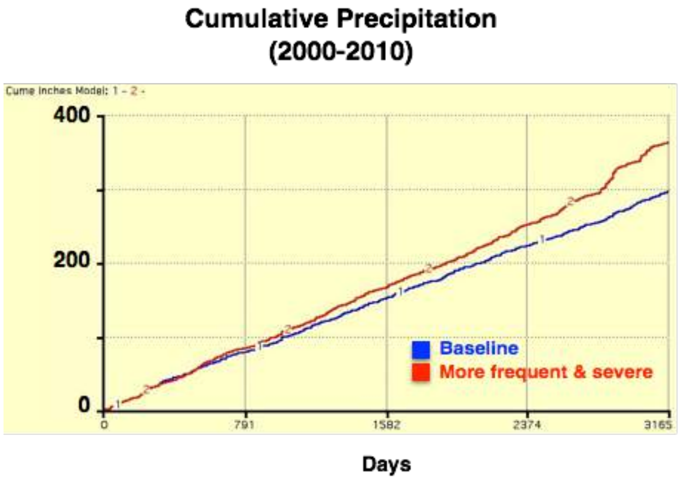
Comparing the model output to historical (below) using these parameters appears to fit the data via an "eyeball" method, based on the above Monte Carlo simulations (n=50).

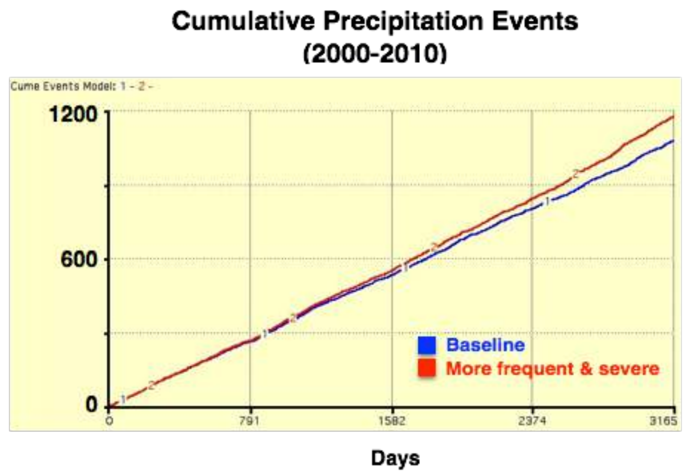




Increases in severity and frequency

GIST allows users to create new precipitation scenarios with rainfall either more severe or more frequent than current conditions (or both). Charts (below) compare the baseline (no change over 10 years) with a scenario where precipitation becomes more frequent and severe.





Limitations and Future Improvements

Water Treatment Capacity

Model currently assumes that Treatment facility removes pollutants required to remain under regulated TMDLs for Post Treatment. A future improvement would be to make this calculation more operational by estimating Max removal (e.g. Tons per day).

Effectiveness over time

Green infrastructure may well become less effective over time, especially if maintenance is not ideal. The current version of GIST doesn't not include any diminution of effectiveness over time, although this could be an additional feature in future versions.

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Portland State University Green Roof Energy Calculator

Appendix

Research to estimate loadings

Table 5. Literature review of pollutant loading rates based on land use classification: bolded values were selected for this study

Land Cover	TSS	TP	TN	Source	Notes
Building	**14**	**0.13**	**1.8**	NYDES – NYS Stormwater Management Design Manual, Appendix A (2001)	Average of residential and commercial roof
Parking	228			NYDES – NYS Stormwater Management Design Manual, Appendix A (2001)	Industrial parking
	27	0.15	1.9	NYDES – NYS Stormwater Management Design Manual, Appendix A (2001)	Residential and Commercial Parking
	15-110	0.06-0.2		USGS Scientific Report 2011-5145 (2011)	
	100	**0.2**	**1.9**	FEA estimates	
Road	**157**	**0.44**	**2.2**	NYDES – NYS Stormwater Management Design Manual, Appendix A (2001)	Average of residential street and urban highway
	150	0.5	3.0	Fuss & O'Neill (2010)	STEPL model estimates
Other Impervious	**173**	**0.56**	**2.1**	NYDES – NYS Stormwater Management Design Manual, Appendix A (2001)	Driveways and other unclassified impervious cover
Open Space	37-602	2.1	9.1	NYDES – NYS Stormwater Management Design Manual, Appendix A (2001)	Lawns/landscaping
	82.5	**0.21**	**2.1**	NHDES (2008)	
	48.5	0.31	1.33	National Stormwater Quality Database v1.1 (2005)	Updated from 0.59 to account for TKN
	70	0.5	1.5	Fuss & O'Neill (2010)	STEPL model estimates
Forest	**77.5**	**0.12**	**1.5**	NHDES (2008)	
	70	0.1	0.2	Fuss & O'Neill (2010)	STEPL/CH2M Hill model estimates

Fecal Coliform Loading Estimates

LCLU Class	Fecal Coliform (colonies/100ml)	Source
Roads	2200	NYDES, NHDES, and NSQD
Parking Lots	1800	NYDES
Buildings	500	NYDES
Other Impervious	1700	NYDES and NSQD
Open Space	5070	NYDES, NHDES, and NSQD
Woodland	300	NHDES

Literature review of pollutant removal percentages based on BMP type

: bolded values were selected for this study.

BMP	TSS	TP	TN	Bacteria	Source	Notes
Wet Basin	80	51	33	70	VT Stormwater Management Manual (2001)	
	80	52	45	70	National Pollutant Removal Performance Database – CWP (2007)	
	75	18		--	UNH Stormwater Center Report (2009)	
	80	50	30	70	Urban Subwatershed Restoration Manual 3 – CWP (2007)	
	80	**50**	**35**	--	NYDES – NYS Stormwater Management Design Manual, Appendix A (2001)	
	95	**60**	**90**	--	Farrell Street Wet Pond Performance Report (VHB, 2011)	
Dry Basin	49	20	24	88	National Pollutant Removal Performance Database – CWP (2007)	
	88	58		--	MNDOT: Water Quality Performance of Dry Detention Ponds with Under-Drains (2006)	12 storms at 1 DD basin in MN, relatively low inflow concentrations.
	61	19	31	--	NPDES Dry Detention Pond Factsheet (2006)	
	50	**20**	**25**	**--**	**FEA Composite Removal Efficiency Estimate**	
Wetland	76	49	30	78	VT Stormwater Management Manual (2001)	
	72	48	67	78	National Pollutant Removal Performance Database – CWP (2007)	
	90+	40		--	UNH Stormwater Center Report (2009)	
	70	50	25	60	Urban Subwatershed Restoration Manual 3 – CWP (2007)	
	80	50	30	--	NYDES – NYS Stormwater Management Design Manual, Appendix A (2001)	
	95	**85**	**75**	--	CSB Farrell Park Gravel Wetland Performance Report (2012)	
Bio-basin	59	5	43	37	National Pollutant Removal Performance Database – CWP 2007	
	100	8		--	UNH Stormwater Center Report (2009)	
	60	**5**	**45**	50	Urban Subwatershed Restoration Manual 3 – CWP (2007)	
Porous Asphalt - Infiltration	95	80	51	--	VT Stormwater Management Manual (2001)	
	89	65	42	--	National Pollutant Removal Performance Database – CWP 2007	
	90	**70**	**50**	--	NYDES – NYS Stormwater Management Design Manual, Appendix A (2001)	
Swirl	60-80			--	Assessment of Hydrodynamic Separators for Stormwater Treatment – Journal of Hydraulic Engineering (2009)	TSS removal highly variable based on inflow particle size and velocity
		15	15	--	Fairfax County LID BMP Factsheet Hydrodynamic Separators (2005)	
	60	**15**	**15**	**--**	**FEA Composite Removal Efficiency Estimate**	Varies based on manufacturer and model.

BMP	TSS	TP	TN	Bacteria	Source	Notes
Storage Tanks	**20**	**5**	**5**	--	**FEA Removal Efficiency Estimate**	