The Effectiveness of Green Infrastructure at Improving Water Quality and Reducing Flooding at the Watershed Scale

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Take home message

Results from site-level and watershed-scale evaluations of the effectiveness of GI show, in general, water quality and flood improvements, but can depend on the type of GI, scale and a number of other factors. There are still many unknowns.

Stormwater modeling is a good way to shed light on some of these unknowns. We examined, specifically, the impact of placement of GI within the watershed and detention v retention.

Results of modeling studies in Siena's local watershed suggest the best type and placement of GI to improve water quality and reduce flooding depends on the management objective. So while there is no "one size fits all" or magic bullet solution, managers should think of "layering" GI strategies to reduce vulnerabilities.

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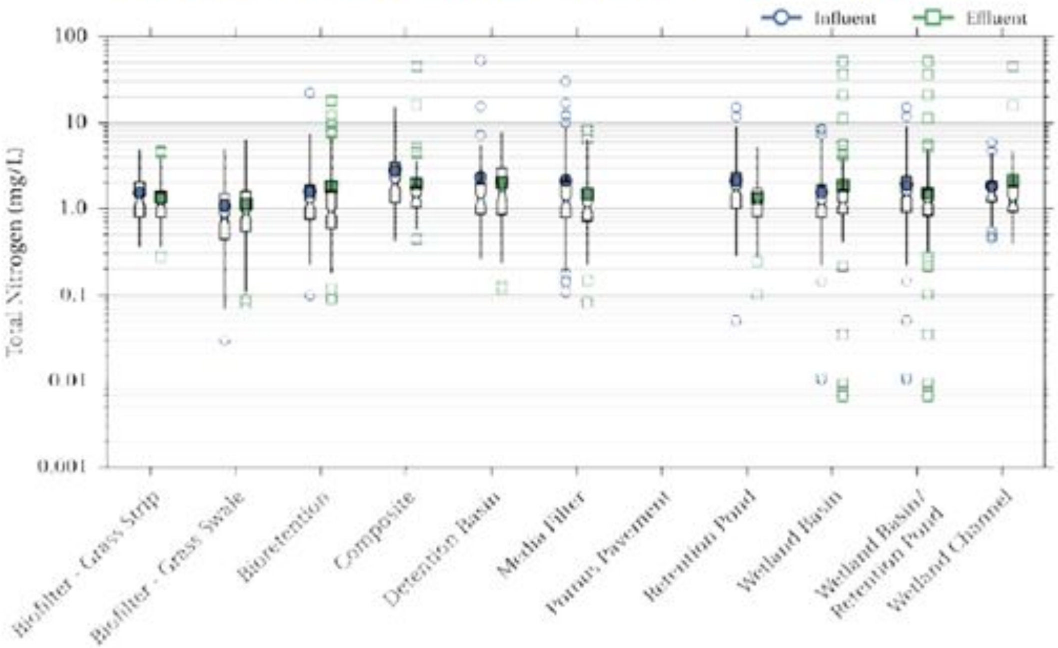
Background

Figure 26. Box Plots of Influent/Effluent Total Nitrogen Concentrations



For example, Center for Watershed Protection (CWP) 2007, Koch et al., 2014, Leisenring et al., 2014, Jefferson et al., 2017, Pennino et al. 2016

Many sources out there summarize and synthesize the performance of GI projects. Show that effectiveness of GI is

- GI type-dependent
- Site-dependent
- Pollutant-dependent

Unsurprisingly, similar inconsistencies when scaling up to the watershed-scale. Additionally,

- Scale-dependent
- Storm-dependent

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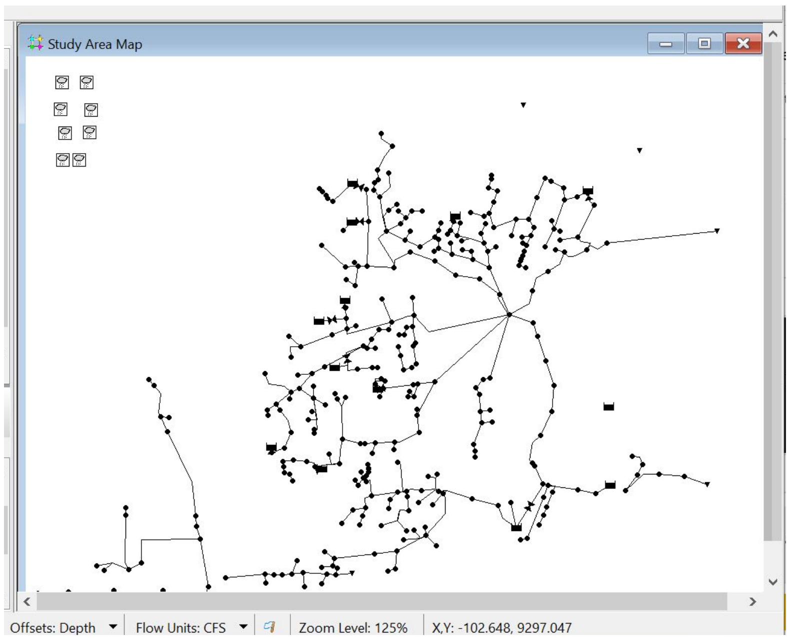
Significance

- Need to develop a framework to better make sense of all of the factors that can impact the effectiveness of GI at the watershed scale.
- Modeling studies can provide important insights by removing confounding variables. You can test just one variable at a time.



- Detention v retention
  - Many studies suggest that detention/infiltration is the key, but previous works suggests that reducing effective imperviousness is not a “one-size fits all solution” (Meierdiercks et al., 2017)
- Centralized v decentralized and scale
  - Previous work also suggests that centralized swm (> 2nd order) is the most effective (Meierdiercks et al., 2009, Smith et al., 2015)
- Drainage network v land surface
  - Drainage network (i.e. fast responding) may be just as important as land surface (i.e. slow responding) elements in controlling response (Robinson et al. 1995, Meierdiercks et al, 2010, Meierdiercks et al, 2017)

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Research question

What is the impact of:

- Detention versus retention-based
- Centralized versus decentralized
- Drainage network versus land surface-located

GI at improving water quality and reducing flooding at the watershed scale?

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Study watershed

Kromma Kill Watershed

- Albany County, NY
- Tributary to the Hudson River
- 20 km^2 drainage area
- Urban/Suburban,19% IMP
- Brownfield Site (heavy metals, PCBs)
- MS4 regulated municipalities
- NYS 303d impaired waterbody
- Siena cited as a source of flooding and water quality problems
- Upstream v. downstream community dynamics
- No stormwater management plan (yet)

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Kromma Kill subwatershed

- 213 acres
- 22.8% impervious (48.7 acres). 2.6% buildings
- 5 stormwater wetlands and one detention pond
- 5.4 total mile drainage network - 95% pipes and 5% surface channels
- Average slope is 7.6%
- Predominant soil type is loamy sand
- 7 drainage points in the study area, the largest with a drainage area of 109 acres.

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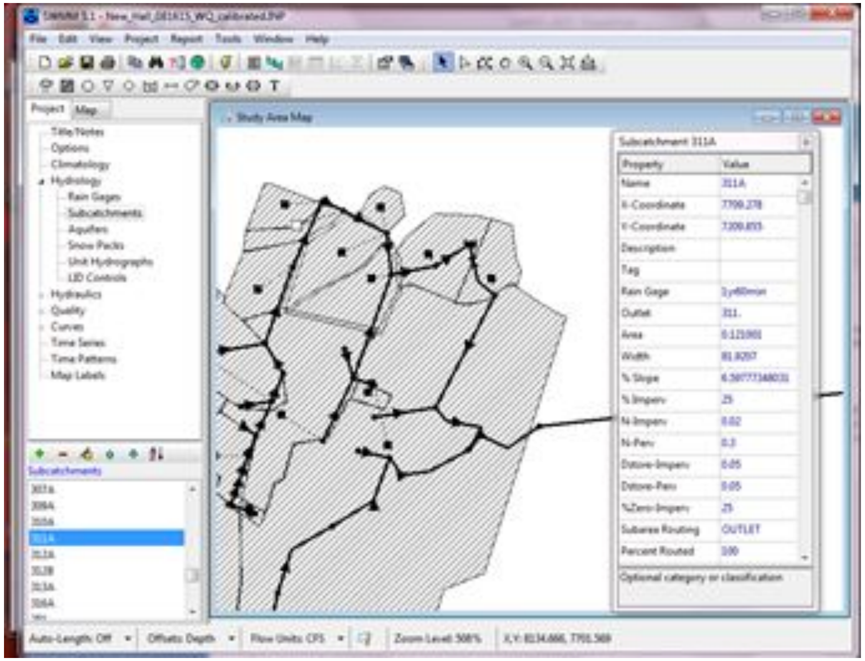
Image source: Siena Facebook

SWMM model development



Removal efficiences		
Pollutant	Wetland	Stormwater Pond
TN	-0.053	-0.21
TDS	-0.75	0.052
NO3	0.73	0.18
TP	0.46	0.22

- EPA SWMM 5.1
- Routes rainfall (minus infiltration) over the land surface, through stormwater pipes, wetlands and detention ponds, and the surface channel network
- Use GIS to construct and parameterize model
- Use field data as forcing, calibration, and validation

Additional details:

- Infiltration: Green-Ampt
- Subarea routing: outlet. Percent routed: 100
- Initial buildup: none
- D-store-Imperv: 0.05. D-store-Perv: 0.05
- Green roof: default parameters
- Removal efficiencies from Leisenring et al. [2014]

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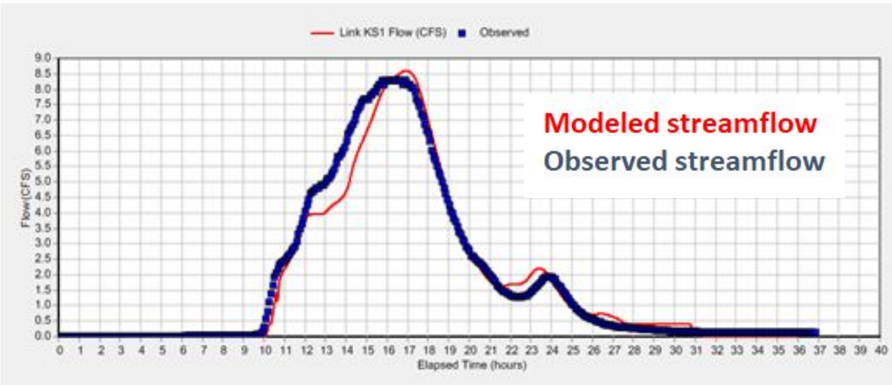
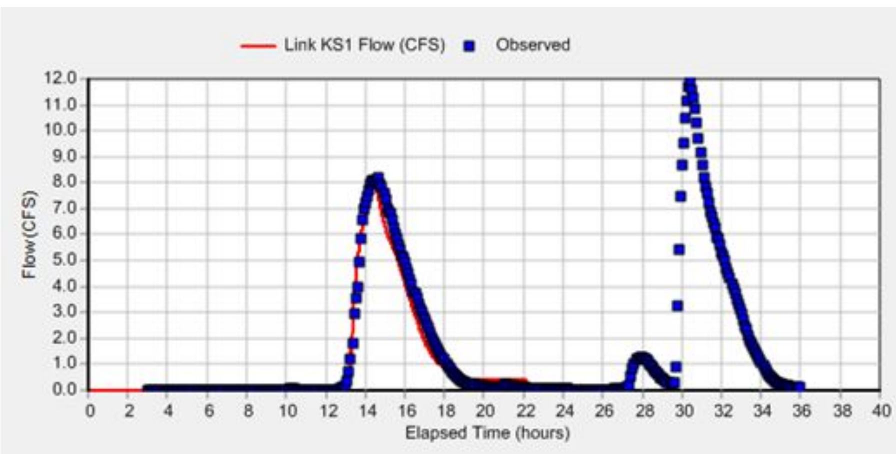
Calibration and validation





Model matched observed hydrograph quite well

Used 5 storms close in magnitude to the 60-minute 1-year design storm

The saturated hydraulic conductivity and the manning's roughness of the pervious and impervious portions of the study area were adjusted manually (but kept within physically realistic values) to match the timing and volume of the observed discharge hydrographs. The calibrated values of Ksat = 0.1875, n-perv = 0.3, and n-imperv = 0.02 were chosen to minimize the differences between modeled and observed discharge

Peak discharge magnitudes between modeled and observed hydrographs for the five storms ranged from 4.3% to 40.5% difference (average = 20.6%).

Differences in volume ranged from 13.2% to 46.2% (average = 27.5%).

Differences in peak timing ranged between 0.3% and 5.7% of the hydrograph duration (average = 3.5%).

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Calibration and validation

Total dissolved solids, nitrate, total nitrogen and total phosphorus were added to the system and the event mean concentration (EMC) function was used to compute pollutant washoff during rain events.

The model was calibrated by adjusting EMC to match concentrations of total dissolved solids and nitrate measured in the field during a storm event close in magnitude to the design storm (TDS = 178.1 mg/L, NO_3 =1.46 mg/L).

For total phosphorus and total nitrogen, the model was calibrated to match values typical of urban runoff (TP = 0.263 mg/L, TN = 2.1 mg/L; James et al., 2010).

These pollutants were chosen for model analyses because they are relatively well characterized in urban environments.

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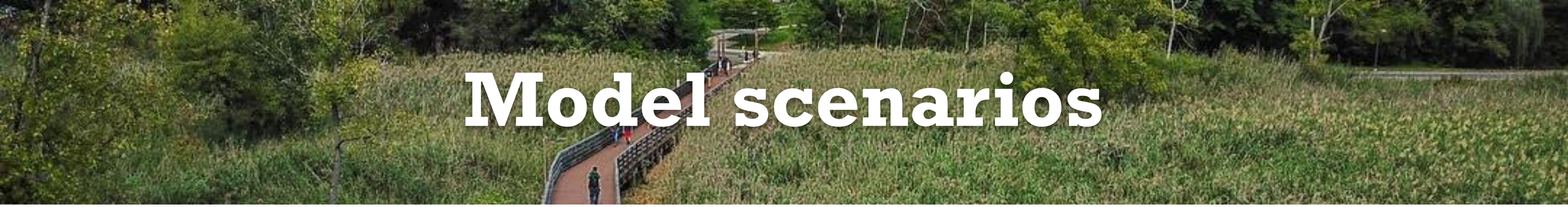


Model scenarios

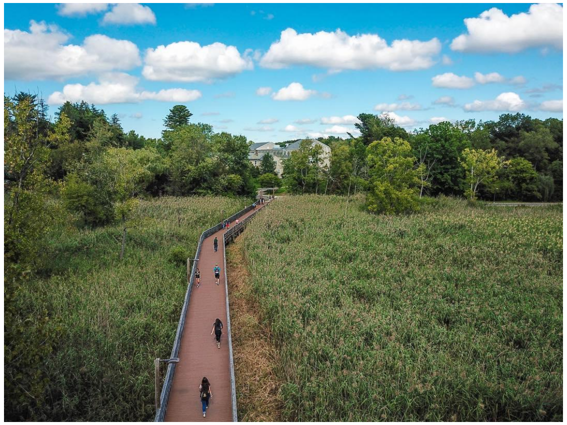
SCENARIO 1: *Business as usual*. The campus watershed as is with one, large centralized wetland

SCENARIO 2: *No wetland (control)*. The watershed with no wetland.

SCENARIO 3: *Decentralized wetlands*. Instead of one large wetland, the watershed with a number of smaller wetlands distributed throughout the watershed capturing the same impervious area as Scenario 1.

SCENARIO 4: *Decentralized green roofs*. Instead of one large wetland, a number smaller greef roofs distributed throughout the watershed capturing the same impervious area of runoff as Scenario 1.

SCENARIO 5: *Decentralized soil management*. Better managed soil throughout the watershed.



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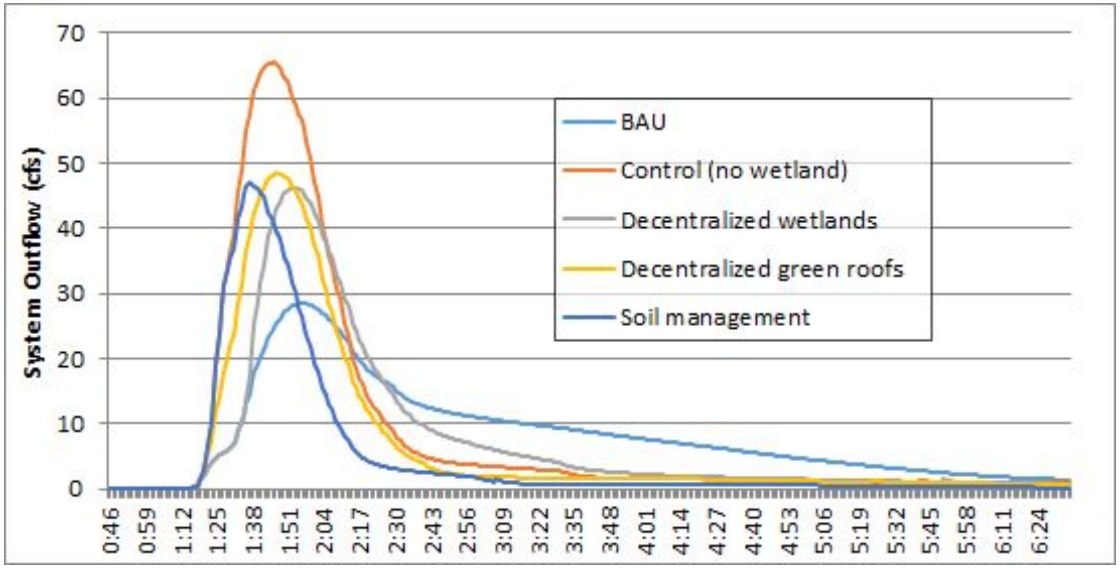
Results: peak discharge

Model Scenario	Peak Discharge (cfs)	% Change
Business as Usual	28.5	-
Control (no wetland, no GI)	65.4	129.7%
Decentralized wetlands	46.3	62.4%
Decentralized green roofs	48.6	70.5%
Soil management	46.9	64.7%



1. The large centralized wetland does significantly reduce peak discharge. More so than any other design scenarios.
2. Decentralized detention v. retention does not have a significant impact on peak discharge.

Results are fairly straightforward and not surprising

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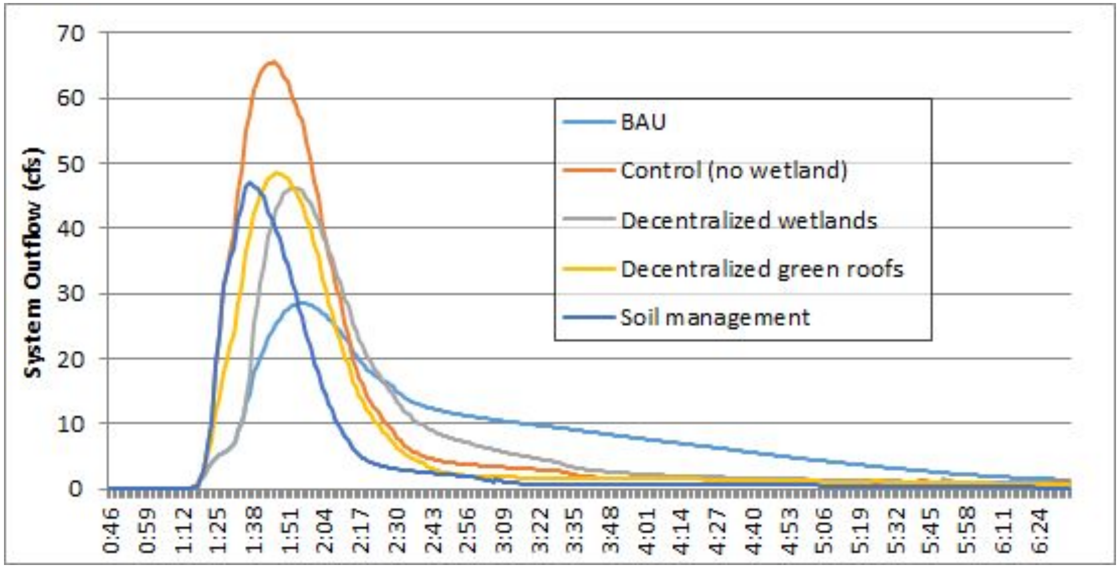
Results: volume

Model Scenario	Runoff Ratio	% Change	Peak Discharge (cfs)	% Change
Business as Usual	0.27	-	28.5	-
Control (no wetland, no GI)	0.29	6.9%	65.4	129.7%
Decentralized wetlands	0.24	-12.2%	46.3	62.4%
Decentralized green roofs	0.21	-21.2%	48.6	70.5%
Soil management	0.16	-42.6%	46.9	64.7%



1. The large centralized wetland does reduce flood volumes, but only by 7%.
2. Decentralized wetlands do provide a modest reduction in volume (12%). But decentralized green roofs reduce volumes by 21%. Decentralized GI works best if its detention/infiltration rather than retention.

Results: water quality

	% Removed (concentration)				% Change			
Model Scenario	TN	TDS	NO3	TP	TN	TDS	NO3	TP
Business as Usual	4.3%	6.3%	55.9%	37.1%	-	-	-	-
Control (no wetland, no GI)	3.6%	5.5%	6.2%	6.4%	-17.5%	-13.2%	-88.8%	-82.7%
Decentralized wetlands	-1.8%	0.5%	18.8%	12.7%	-140.4%	-91.6%	-66.4%	-65.8%
Decentralized green roofs	40.0%	43.0%	43.5%	43.7%	825.1%	581.0%	-22.1%	17.7%
Soil management	47.8%	47.8%	47.8%	47.8%	1004.9%	658.2%	-14.4%	28.8%

	% Removed (lbs)				% Change			
Model Scenario	TN	TDS	NO3	TP	TN	TDS	NO3	TP
Business as Usual	30.0%	31.4%	67.7%	54.0%	-	-	-	-
Control (no wetland, no GI)	24.5%	26.0%	26.6%	26.7%	-18.2%	-17.2%	-60.7%	-50.5%
Decentralized wetlands	34.4%	35.9%	47.7%	43.7%	14.8%	14.2%	-29.6%	-19.0%
Decentralized green roofs	56.5%	58.6%	59.0%	59.1%	88.3%	86.4%	-12.9%	9.5%
Soil management	61.1%	61.1%	61.1%	61.1%	103.7%	94.4%	-9.8%	13.1%

Removal efficiences		
Pollutant	Wetland	Stormwater Pond
TN	-0.053	-0.21
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Leisenring et al. [2014]

Tempting to say that detention/infiltration is always going to be the best management strategy to improve water quality, but this is not the case for all pollutant types.

Wetlands are very efficient at removing NO3, so replacing with green roofs reduces water quality.

Replacing the centralized wetland with several decentralized ones, increased the concentration of all pollutants because runoff volumes were reduced.

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Summary and management implications

- GI that targets the drainage network (i.e. fast responding) is going to have biggest impact on peak discharge and "flashiness".
- GI that targets the land surface (i.e. slower responding) elements of the watershed and promotes detention/infiltration will have the biggest impact on volumes.
- For water quality, detention/infiltration not always best strategy. Reducing volumes could simply increase concentration without actually reducing pollutant loads. And a wetland that retains (rather than detains/infiltrates) could remove more pollutants than a green roof and therefore, you are better off letting runoff flow through the wetland.
- No GI magic bullet, but rather different types and locations should be implemented via the Swiss Cheese Model

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