Green Infrastructure – Triple Bottom Line Benefits at Different Scales

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AWRA-PMAS
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Design  
eDD, others

Construction  
Others

Monitoring  
Drexel SWRL
GI Monitoring Network
The Sustainable Water Resource Engineering Lab at Drexel University

New York City sites

Philadelphia sites
Commitments to GI

- **NYC (2010)**: >$1.5 billion over 25 yrs
  - Capture first inch from 10% of impervious surfaces
  - $187 million in first 5 years (200 bioswales this year)

- **Philadelphia (2009)**: >$1 billion over 25 yrs
  - Capture first inch of rainwater from ~47% of impervious surfaces in CSO districts
  - ~744 acres in first 5 years

- **Other committed/almost committed cities:**
  - Syracuse, Milwaukee, Kansas City, Portland, Chicago, St. Louis, Washington DC, Seattle, Cincinnati, Louisville
Triple (Quadruple?) Bottom Line

- Economic scalability
- Ecological benefits
- Social value
- Climate change mitigation/adaptation value
Triple (Quadruple?) Bottom Line

- Economic scalability
- Ecological benefits
- Social value
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Lot-scale
Streetscape
Wetland
West Ward Pride Garden (Newark, NJ)
Percent of storm volume infiltrated: 4 - 69%

<table>
<thead>
<tr>
<th>Rain Event</th>
<th>Date</th>
<th>Day</th>
<th>Total Storm Depth (mm)</th>
<th>Total Storm Volume (m³)</th>
<th>Storm Duration (hrs)</th>
<th>Average Intensity (mm/hr)</th>
<th>Antecedent Dry Period (days)</th>
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<th>Available Detention Volume in Cistern (m³)</th>
<th>Hours at Capacity in Cistern</th>
<th>Total Drawdown Time (hours)</th>
<th>Infiltrated Volume (m³)</th>
<th>Percent Storm Infiltrated</th>
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Low cost stormwater management on underutilized urban spaces
STORMWATER FALLING ON 3,600SF IMPERVIOUS ROOF CATCHMENT DURING ONE-INCH STORM = 2,244 gallons

ENGINEERED MAXIMUM STORAGE VOLUME = 3,638 gallons

% OF STORMWATER DETAINED DURING ONE-INCH STORM = 100%
West 150th Street, NYC
STORMWATER FALLING ON 2,648SF IMPERVIOUS ROOF DURING ONE-INCH STORM  
= 1,651 gallons

ENGINEERED MAX STORAGE VOLUME  
= 4,040 gallons

% OF ONE-INCH STORM DETAINED/RETAINED  
= 100%
The Sixth Street Green Corridor (Brooklyn, NY)

6th street between 2nd and 4th avenues
Section (proposed modification to NYCDEP standard bioswale)

PERFORATED CAP WITH
GEOTEXTILE FABRIC TO BE PLACED
1" BELOW MAX. SURFACE PONDING
ELEVATION

12" DIA. SOLID HDPE PIPE
PLANTING MEDIUM
PVC COUPLER
12" DIA. PERFORATED
HDPE PIPE WRAPPED IN
GEOTEXTILE FABRIC
PVC COUPLER
12" DIA. SOLID HDPE PIPE

MAX. SURFACE PONDING

CONCRETE SIDEWALK
WITH 6" FOUNDATION
MATERIAL

GRAVEL WRAPPED IN
GEOTEXTILE FABRIC
EXISTING
SUBGRADE

Elevation

Construction to begin 2013
ABC Carpet (Bronx, NY)

Impervious parking lot draining to Bronx River

Underutilized riparian land
Inflow from parking lot

Overflow to river
Water level in wetland (meters left axis)
Inflow from parking lot (cfs right axis)
Bronx River stage (meters left axis)
8000 gallons of stormwater (20 cm over 1625 sf wetland area) evaporated over one 10 day period.
Flushing Meadows Corona Park (Queens, NY)

Underutilized lawn

Impervious parking lot (drains to lake)
Wetland projects

Streetscape bioswales

Lot level stormwater management

Construction Cost¹ Versus Catchment Area²

¹ Some construction costs are estimated
² Catchment area includes GSI facility area
Wetland projects
Streetscape bioswales
Lot level stormwater management

The larger the catchment area, the greater overall economy of scale but with change in GI system typology.

Construction Cost$^1$ Versus Catchment Area$^2$

$^1$ Some construction costs are estimated
$^2$ Catchment area includes GSI facility area

Graph showing the relationship between construction cost and catchment area.
Wetland projects

Streetscape bioswales

Lot level stormwater management

Construction Cost\(^1\) per Square Foot of Catchment Area\(^2\) Versus Catchment Area

\(y = -0.0201x + 72.416\)

\(y = -0.0004x + 14.84\)

\(y = -9E-05x + 14.939\)
The larger the catchment area, the lower the unit costs but with change in GI system typology.
Triple (Quadruple?) Bottom Line

Economic scalability

Ecological benefits

Social value

Climate change mitigation/adaptation value

Interception

Evaporation

Infiltration
More specifically…..

Are the type and scale of GI projects we are implementing “restoring pre-development hydrology”?

Are the ecological services derived from GI meaningful, in an infrastructure context?
Infiltration capacity of conventional and new engineered permeable urban spaces

Sites: New York City and Philadelphia

Method: Cornell Sprinkle Infiltrometer

Alizadehtazi et al (in revision)
Conventional Permeable Urban Spaces

Vegetated Courtyard

Backyard

Urban Park

Courtesy of USDA NRCS
Conventional Permeable Urban Spaces

Tree Pits

Without guards

With guards

Courtesy of Tatiana Morin
New Engineered Permeable Urban Spaces

Porous Pavers

Porous Asphalt

Porous Rubberized Safety Materials

Concrete

Porous Standard

Courtesy of USDA NRCS
New Engineered Permeable Urban Spaces

Bioretention “Greenstreets”
Results

The diagram illustrates the infiltration rate (cm/min) for various land uses. The x-axis represents different land uses: Urban Parks, Tree Pits (without guards), Tree Pits (with guards), Porous Pavers, Backyards, Bioretention Facilities, Porous Rubberized Safety Materials, Porous Asphalts, and Porous Concrete. The y-axis shows the infiltration rate ranging from 0 to 0.8 cm/min. The colors indicate different infiltration rates: high (green), unclear (pink), middle (yellow), and low (red).
Conventional spaces (parks and tree pits without guards) were the sites with the lowest infiltration capacity. An engineered permeable space consistently presented the highest infiltration capacity.

Take home message: we can engineer more permeability into our heavily developed landscapes.
Can we accelerate urban evaporation (= mitigate the urban heat island) by directing stormwater to urban green spaces?
Ground surface

Weighing Lysimeter
Not To Scale
Sites

Ecological reference: Alley Pond Park (Queens, NY)

Summer

Winter
Sites

Two different bioretention “Greenstreets”

**Colfax site:** surrounded by curb

**Nashville site:** hydraulically connected to surrounding street and sidewalk catchments through curb cut (11:1)
Sample Lysimeter data

Bioretention Area (Greenstreet) - Nashville
Lysimeter Mass and Precipitation (Onsite and Furmanville)

Precipitation, Furmanville (mm/day)
Precipitation, Onsite (mm/day)
Lysimeter Mass (kg)
Comparison of Results

- Colfax (surrounded by curb)
- Nashville (catchment:bioretention ratio = 11:1)
- Alley Pond Park

Time (two months)
Comparison of Results

Evaporation = reduction in mass over dry spells

Nashville shows the greatest reduction in mass (e.g. accelerated evaporation)

Annual averages:
Nashville    2.3 mm/d
Colfax:      1.96 mm/d
Alley Pond: 0.58 mm/d

By irrigating with stormwater we can accelerate ET over reference conditions, accelerating heat loss as well (1 gm = 595 calories)
Intercepting precipitation with new tree canopies

Why?

- Trees bring lots of benefits (e.g. shade, wind break, habitat, aesthetics)
- In forests, 10-40% of rainfall is intercepted (Zinke, 1967)
A preliminary assessment of the stormwater benefits of the Million Trees initiative at its halfway point
BUT HOW MUCH WATER IS THIS?

2.6 million cubic meters = 686 million gallons
Citywide volume of rainfall intercepted by 240,000 street trees > annual volume of CSOs offset by grey infrastructure.… Not Bad!
Triple (Quadruple?) Bottom Line

- Economic scalability
- Ecological benefits
- Social value
- Climate change mitigation/adaptation value

New forms of partnerships?
Neighborhood revitalization?
Challenge of scaling up

Uncertainty in Performance

Uncertainty in Cost

% reduction in annual runoff

Year

TOTAL COST: NPV (k $)

Year

Uncertainty due to climate, physical performance metrics

Uncertainty due to unit costs of GI installations

Social / institutional uncertainty associated with rate of adoption
Project goals:

- Answer a practical question:
  - Will PWD achieve its goal of promoting stormwater capture on 47% of the impervious surfaces in neighborhoods in combined sewer areas within 25 yrs?

- Develop a new modeling platform:
  - Simulation of spatiotemporal emergence of GSI in a sample Philadelphia neighborhood
  - Realistic depiction of interacting spatial, economic, legal, physical, and policy factors

Collaborators: Alex Waldman, Katy Travaline, Tim Bartrand, Juliet Geldi, Gavin Riggal, Chariss McAfee, Charles Loomis, Franco Montalto

Disclaimer: results of this study do not represent any official position by PWD
Study Site: Point Breeze (Phila, PA)

Neighborhood Statistics:
Area: ~ 175 hectares
10,363 lots
18.5% of lots are vacant
75% of lots are residential
82% of surface impervious
Pop: 21,200
35% below poverty line
82% Af. Am. 10% Asian
Methods: Agent-Based Models

- A family of computational models, typically custom built, that simulate the “bottom up” actions and interactions of autonomous “agents” in a network environment.

- Can be used to develop insights into how agent behavior and multi-domain interactions affect system performance.
Initializing Agent Attributes through empirical methods

- **PWD** → Implementation & Adaptive Management Plan (PWD initiated, GSI following public works, private GSI)
- **Property** → Geospatial data sets; census and other aggregate data downscaled using stochastic methods
- **Property owners, other city agencies, community organizations** → Outreach activities
  - Participant-observation
  - Interviews
  - Community Street Fair
  - Questionnaires
  - Policy Official Outreach
Behavioral rules: PWD

PWD decision sequencing (sample)

- Assemble current GSI opportunities
  - PWD-initiated
  - Public works
  - Private

- Compute PWD leverage
  - Compute GA installed to-date and GA scheduled for current year
  - Determine current construction costs
  - Set aside Raincheck budget
  - Lookup PWD leverage

- Implement Private strategies
  - Offer all owners w/o GSI opportunity to participate
  - PWD pays 80% of const. costs (limited to funds set aside for Raincheck)

- Implement PWD-initiated strategies
  - Sites selected by PWD
  - May include funds from other organizations
  - Must be possible with current leverage

- Implement GSI following Public Works
  - PWD offers Streets/Parks/Schools current leverage
  - Offer accepted or declined
  - Offers made until annual GA goal met

Program complete (30 years?)
Behavioral rules: Property owners

Property owner decision sequencing

Collect information
- Social network
- Local conditions

Assess information
- Values
- Trust

Decide (stochastic)
- Index
- Constraints

Inform
- Social network
- Physical environment
Sample simulations:

**Model 1:** Focus on managing runoff originating on public property on public land.
Vacant Land in Philadelphia

Three-Quarters of the 40,000 Vacant Parcels Located Within the City are Privately Controlled

- Non City Entities 76.9%
- Public Property 14.3%
- RDA 7%
- PHDC 1.7%
- Other City Entities 0.1%

Sample simulations:

Model 2: Also allows PWD to manage residential stormwater on publically owned vacant parcels of land.
Sample simulations:

**Model 3:** Adds in a GSI banking program whereby a third party acquires privately owned vacant land and sells GSI credits to offset stormwater impacts of development elsewhere.
Visualization of Results (sample run)
Time Evolution of Community-Scale GSI in Point Breeze

Model 1

Model 2

Model 3

Net Greened Acres Associated with each GSI Strategy After 30 Years

Model 1

Model 2

Model 3

Frequency of Different GI Strategies After 30 Years

Model 1

Model 2

Model 3

Not available
Time Evolution of Community-Scale GSI in Point Breeze

- Model 1
- Model 2
- Model 3

Net Greened Acres Associated with each GSI Strategy After 30 Years

- Model 1
- Model 2
- Model 3

Frequency of Different GI Strategies After 30 Years

- Scenario 1
- Scenario 2
- Scenario 3

Only Model 3 gets close to achieving the 47% goal

Role of privately-owned vacant land in achieving coverage goals at the neighborhood scale is key

Not available
Though models 1 and 2 arrive at a similar overall mean % green, there is more uncertainty in Model 2 due to uncertain spatial placement of early installations (path dependency of budget allocations and early GI placement decisions).
rowing strategies (bump outs and porous pavement) will account for a large percentage of greened acres in all three models.

In Model 3, GSI on banked private land could, however, account for even more greened acres.

Importance of public/private partnerships for changing the urban watershed.
Animated results

Model 1

Model 3
How would the results differ in a neighborhood with a different spatial distribution of vacant land?
Uniform distribution leads to greater neighborhood greening

Could indicate that dedicating some vacant land to stormwater management could help the city achieve its greening goals....

Can these become new community open-space assets??
Triple (Quadruple?) Bottom Line

- Economic scalability
- Ecological benefits
- Social value

Climate change mitigation/adaptation value
Adaptation Value

Response of Nashville Greenstreet to Hurricane Sandy

Nashville Bioretention “Greenstreet”

Curbcut inlet
Mitigation value
A Life Cycle Comparison of “grey” and “green” approaches to CSO reduction (Bronx, NY)

De Sousa et al 2013
Three strategies

- Distributed green approach
- Detention tank with pump
- Detention tank with treatment/discharge
Life Cycle Assessments

- Climate System
- Source Water Body
- Water Supply System
- Study Watershed
- Stormwater Collection System
- Wastewater Collection System
- Combined Collection System
- Receiving Water Body
- Vadose Soil Zone
- Groundwater System

System Boundary

De Sousa et al 2013
Analysis considered

• GHG released during
  – Project installation
  – 50 yrs of operation and maintenance
  – At WWTP with the project in place

• Also considers GHG associated with
  – Shade provided by trees near residences
  – Wind blocked by trees near residences
  – Carbon permanently sequestered in trees
Watershed modeling

<table>
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<tr>
<th>CSO reduction strategy</th>
<th>Change in volume of untreated sewer overflows per year over do-nothing case</th>
<th>Change in flow to the Hunts Point Wastewater treatment plant over do-nothing</th>
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<tbody>
<tr>
<td>1. Green</td>
<td>Down</td>
<td>Up</td>
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<tr>
<td>2. Grey- detention tank</td>
<td>Down</td>
<td>Up</td>
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<tr>
<td>3. Grey- treat and discharge</td>
<td>Down</td>
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De Sousa et al 2013
LCA Comparison

GHG emissions implied by the GI strategy significantly lower than Scenarios 2 and 3.
By year 20, vegetation has completely compensated for required O&M activities.
Even after considering all of the uncertainty, the emission of the GI strategy significantly lower.
Concluding Remarks

• Quantification of actual TBL benefits of urban GI is still at the early stages
• At the site and watershed scale, the opportunity for making urban watersheds more functional is great.
• Cost-effectiveness, however, is contingent upon selection of the proper strategy for the site, and creating the right partnerships
• These partnerships are also an opportunity for a wide range of stakeholders to assist in, and benefit from this unprecedented phase of investment in cities
Thanks!

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