Advances in Raingarden Design
An Engineered Approach
Moving to Resilient Stormwater Systems

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Urbanization of the Hydrologic Cycle


Codicil to Ben Franklin's Will - 1789

... And, having considered that the covering a ground plot with buildings and pavements, which carry off most of the rain and prevent its soaking into the Earth and renewing and purifying the Springs, whence the water of wells must gradually grow worse, and in time be unfit for use, as I find has happened in all old cities...
To meet these goals requires a resilient engineered system, based upon the interactions of the soil, water, and vegetation, related to the climate, and supported through design, construction, maintenance, and monitoring.

Philadelphia Water Department Targets

Key:
- Image adapted from: Hoban and Wong, WSUD (2006)
China Sponge City

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The Evolution of Infiltration

- 2000 - Recognized as the mechanism to remove stored volume
  - Focus on surface storage and soil void space
  - Infiltration rates considered constant
  - Concerns over interference from back to back storms
  - No expectations for extreme events

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Traffic Island Event: Average Rainfall Rate / Infilt. Chart

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Image adapted from: Hoban and Wong, WSUD(2006)
The Evolution of Infiltration

- Current Knowledge - Soil Physics Based
  - Saturated Hydraulic Conductivity
  - Vadose (unsaturated zone)
  - Understanding of soil suction, and temperature effects
  - Plant available moisture
  - Understanding of soil suction, and temperature effects
  - Importance of vegetation
  - Plant available moisture
  - Macropores
  - Importance of vegetation
  - Expectation for performance for extreme events
  - Role of infiltration supported by science

- Infiltration Design Elements
  - Soil Composition/Compaction
  - Soil Water-Moisture
  - Temperature
  - Underlying Soil
  - Climate patterns
  - Footprint
  - TIME!

The Evolution of Evapotranspiration

- 2000 - Recognized as important

Regional Evapotranspiration (ET)
Observed Data

• Villanova Green Roof Lysimeter

<table>
<thead>
<tr>
<th>Historical</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
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</thead>
<tbody>
<tr>
<td>Rainfall (mm)</td>
<td>845</td>
<td>1152</td>
<td>819</td>
<td>1345</td>
<td>901</td>
<td>948</td>
</tr>
<tr>
<td>ET (mm)</td>
<td>~600</td>
<td>764</td>
<td>718</td>
<td>990</td>
<td>690</td>
<td>660</td>
</tr>
<tr>
<td>ET (% rainfall)</td>
<td>60%</td>
<td>88%</td>
<td>74%</td>
<td>77%</td>
<td>75%</td>
<td>80%</td>
</tr>
</tbody>
</table>


The Evolution of Evapotranspiration

• Recognized as a contributing part of a GI system’s water balance
  • Instrumental in GI functioning of GI
  • Removes stored water volume
  • Restores soil storage capacity
  • Maintains healthy plant life
  • Role of ET supported by science

• ET Design Elements
  • Penman Montel — Hargraves Eq.
  • Meteorological Conditions
  • Vegetation
  • Soil/Water Availability
  • TIME!


Treatment Train
Villanova Treatment Train
Superstorm Sandy
- Rainfall: 11 cm
- Volume of runoff: 101 m³
- Total system capture: 98 to 100 m³
- Overflow: 1 to 3 m³
- Average rainfall intensity: 0.065 cm/hr


Villanova Treatment Train
Large Event Performance


Zoo Rain Gardens
Design:
4.9 cm 1.9 in impervious
Static Volume

Cara Albright
Lessons Learned From a Decade of Research

To meet these goals requires a resilient engineered system, based upon the interactions of the soil, water, and vegetation, related to the climate, and supported through design, construction, maintenance, and monitoring.
Lesson # 1 – Water flows downhill and doesn't turn left.

Lesson # 2 – Understand your drainage area
LIDAR / GIS

Lesson # 3 – Build it RIGHT!
Lesson # 4 – Vegetation is a Design Element

Lesson # 5 - Deal with Trash and Leaves - Maintenance

Lesson # 6 – Make it a Community Asset!
Lesson #7 – Monitoring Is Needed….

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  • Conor Lewellyn

Managed Release Concept
What is MRC?
The MRC BMP has been created to provide a volume and water quality benefit for areas where infiltration is not feasible. It is designed to provide volume management and filtration through slow flow release from a restricted BMP underdrain.

Where can it be used?
- MRC is limited to project areas or subareas where infiltration:
  - is extremely limited*
  - not feasible (i.e., groundwater and/or regularly occurring seasonally high-water tables within one foot of the bottom of the BMP’s soil media)
  - undesirable (e.g., sinkhole-prone areas or contaminated soils).

What does it look like?
MRC can be incorporated within specific BMPs
Ex: Bioretention, pervious pavements with storage bed, underground detention, and others if they meet MRC design standards.
What does it look like?

- Placed so that it captures the runoff from a 1.2” – 2 hour storm
- MRC BMP are highly recommended to have an internal water storage (IWS)
- IWS have been shown to provide improved water quality and ET benefits

What are the main design parameters?

- Release rate should not exceed 0.01 cfs (rounded to the nearest hundredth) per acre of equivalent impervious area
- IWS ≥ 1 foot deep (assume ½ available during storms for vegetated systems)
- Soil media depth of a facility (including the IWS) ≤ 4 feet and ≥ 2 feet
Maximum ponding time:
• Defined as the time after end of storm event for stored surface water to recede to the soil surface
• Limited to 72 hours

Maximum ponding depth:
• 2 feet (2-yr/24-hr)

What are the main design parameters?
• Post-construction 2-year/24-hour storm peak flow → pre-construction 1-year/24-hour storm level
• Max depth 2 feet

• Bypass the 10-, 50- and 100-year/24-hour storm events
• If you really really - can’t... four feet maximum ponded depth
What are the main design parameters?

MRC BMP provides water quality demonstration if it is a:
- Vegetated MRC BMP
- Porous pavement MRC BMP with adequate vacuum street sweeping maintenance regime
- Underground storage chamber - pre / post treatment
- 85% of TSS + P
- IWS – Primary N

Design Example

Rainfall
- NOAA 24-hour type C curve distribution
- NOAA 14 depths for Philadelphia
  - 2.8", 3.4", 4.8", 6.8", 7.8" for 1-, 2-, 10-, 50-, 100-year/24-hour events
- Post-construction:
  - CN of 98: impervious surface
  - Tc: 5 minutes
- Pre-construction:
  - CN of 74: meadow in good condition over HSG C soil
  - Tc: 15 minutes

Design Example

Rain garden
- 30% soil media void space to mimic soil storage recovery through ET and infiltration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>BMP footprint area</td>
<td>0.07 ac</td>
</tr>
<tr>
<td>Contributing area (all impervious)</td>
<td>0.8 ac</td>
</tr>
<tr>
<td>Ponding depth</td>
<td>1.1 ft</td>
</tr>
<tr>
<td>Media depth</td>
<td>2.5 ft</td>
</tr>
<tr>
<td>IWS depth (included within soil media depth)</td>
<td>1 ft</td>
</tr>
<tr>
<td>Infiltration rate</td>
<td>0.1 in/hr</td>
</tr>
<tr>
<td>Void space</td>
<td>30%</td>
</tr>
</tbody>
</table>
Design Example Results
1-inch Runoff Event

Maximum: 0.01 cfs
No overflow

Design Example Results
2-year/24-hour Storm Event