

VILLANOVA UNIVERSITY
COLLEGE OF ENGINEERING

CENTER FOR RESILIENT
WATER SYSTEMS

Advances in Raingarden Design An Engineered Approach

Moving to Resilient Stormwater Systems

With
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Urbanization of the Hydrologic Cycle

Philadelphia Water (PWD) Stormwater Management Guidance Manual

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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...

Philadelphia Water Department Historical Collection

PHILADELPHIA

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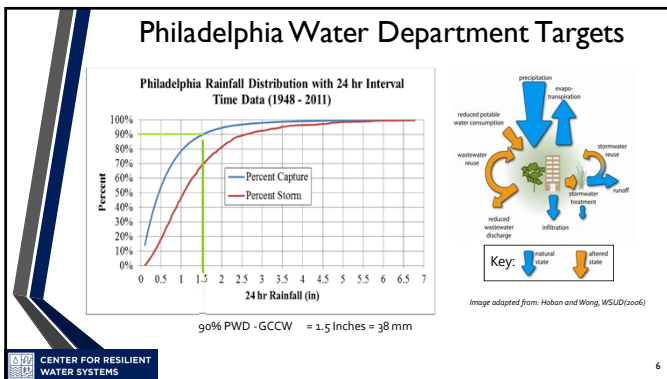
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The Evolution of Infiltration

- Current Knowledge - Soil Physics Based
 - Saturated Hydraulic Conductivity
 - Vadose (unsaturated zone)
 - Understanding of soil suction, and temperature effects
 - Importance of Vegetation
 - plant available moisture
 - macropores
 - 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!

Storm Size	Sample Size	Average Volume Reduction
Small (<1.27 cm (<0.5 in))	115	100%
Medium (1.27-2.54 cm (0.5 - 1.0 in))	127	97%
Large (>2.54 cm (> 1.0 in))	122	50%


Source, L. Lord Thesis 2013

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The Evolution of Evapotranspiration

- 2000 - Recognized as important



Zaremba, G. J., Traver, R. G., & Wadzuk, B. M. (2016). Impact of drainage on green roof evapotranspiration. *Journal of Irrigation and Drainage Engineering*, 142(7), 04016022.

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Regional Evapotranspiration (ET)

Estimated fraction of precipitation lost to evapotranspiration 1971-2000


- 0.0 - 0.09
- 0.1 - 0.19
- 0.2 - 0.29
- 0.3 - 0.39
- 0.4 - 0.49
- 0.5 - 0.59
- 0.6 - 0.69
- 0.7 - 0.79
- 0.8 - 0.89
- 0.9 - 0.99
- 1.0 - 1.09
- 1.1 - 1.19
- 1.2 - 1.29

CENTER FOR RESILIENT WATER SYSTEMS 13 Sanford and Sebnick (2013)

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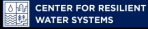
Observed Data

- Villanova Green Roof Lysimeter



	Historical	2009	2010	2011	2012	2013	2014
Rainfall (mm)	845	1152	819	1345	894	901	848
ET (mm)	~600	784	718	990	690	680	675
ET (% rainfall)		68%	88%	74%	77%	75%	80%

Zaremba, G. J., Traver, R. G., & Wadzuk, B. M. (2016). Impact of drainage on green roof evapotranspiration. *Journal of Irrigation and Drainage Engineering*, 142(7), 04016022.

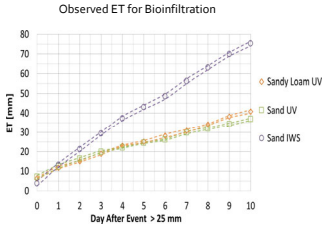

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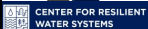
The Evolution of Evapotranspiration

- 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 Monteith - Hargreaves Eq.
 - Meteorological Conditions
 - Vegetation
 - Soil Water Availability
 - TIME!

Observed ET for Biofiltration



Hess, A. (2017). Rain Garden Evapotranspiration Accounting. Dissertation, Villanova University


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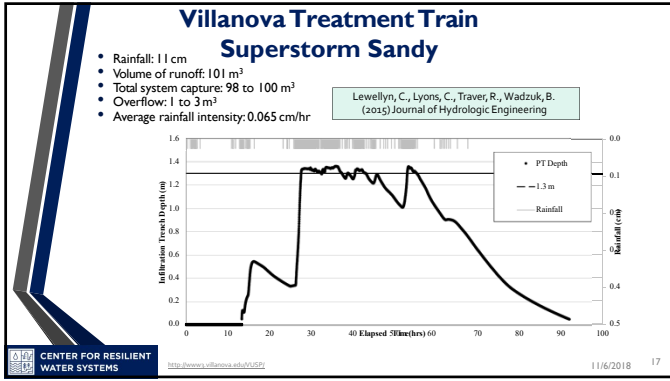
Treatment Train



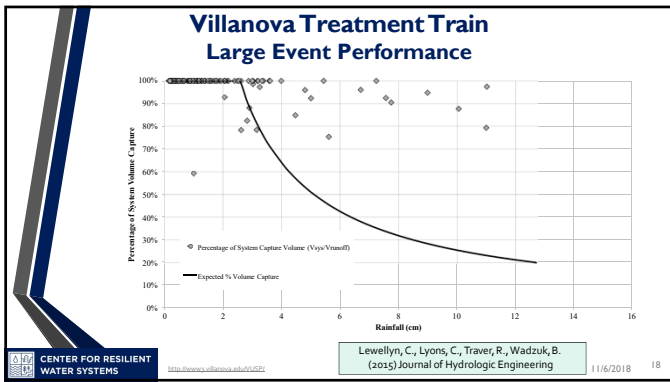


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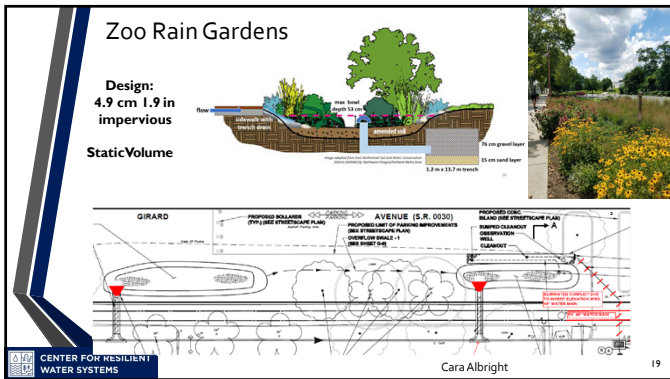
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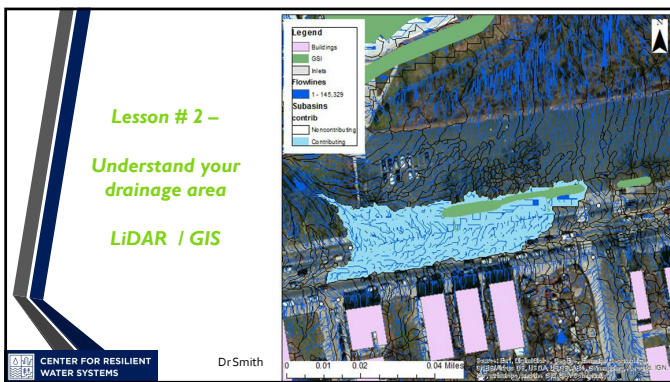
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Lesson # 4 – Vegetation is a Design Element



Thanks to Allen Davis

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Lesson # 5 - Deal with Trash and Leaves - Maintenance



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Lesson # 6 – Make it a Community Asset!



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Lesson # 7 – Monitoring Is Needed

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Acknowledgements

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- USEPA
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Managed Release Concept

Evapotranspiration

Overflow/by-pass

Ponding depth

Media depth 18" depth

Managed release

Upturned elbow

Perforated underdrain surrounded by gravel

Infiltration (as native media allows)

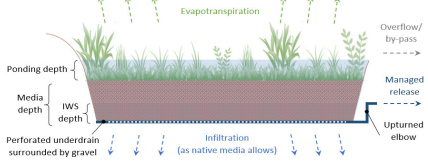
DEPARTMENT OF ENVIRONMENTAL PROTECTION
Bureau of Clean Water

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VILLANOVA-URBAN HYDROLOGICAL PARTNERSHIP

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What is MRC?

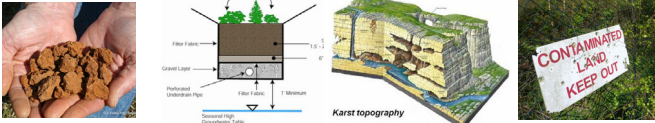
The MRC BMP has been created to provide a volume and water quality benefit for areas where infiltration is not feasible. It is designed to provide volume management and filtration through slow flow release from a restricted BMP underdrain.



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Where can it be used?

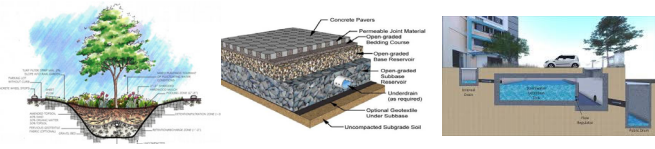
- MRC is limited to project areas or subareas where infiltration:
 - is extremely limited*
 - not feasible (i.e., groundwater and/or regularly occurring seasonally high-water tables within one foot of the bottom of the BMP's soil media)
 - undesirable (e.g., sinkhole-prone areas or contaminated soils).



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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



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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

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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

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What are the main design parameters?

- IWS \geq 1 foot deep (assume $\frac{1}{2}$ available during storms for vegetated systems)
- Soil media depth of a facility (including the IWS) \leq 4 feet and \geq 2 feet

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What are the main design parameters?

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)

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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

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What are the main design parameters?

- Bypass the 10-, 50- and 100-year/24-hour storm events
- If you really really - can't... four feet maximum ponded depth

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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

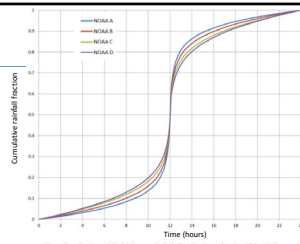


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Design Example

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



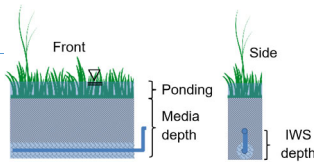
Plot of A, B, C, and D 24-hour rainfall distributions for the Ohio Valley and neighboring states.



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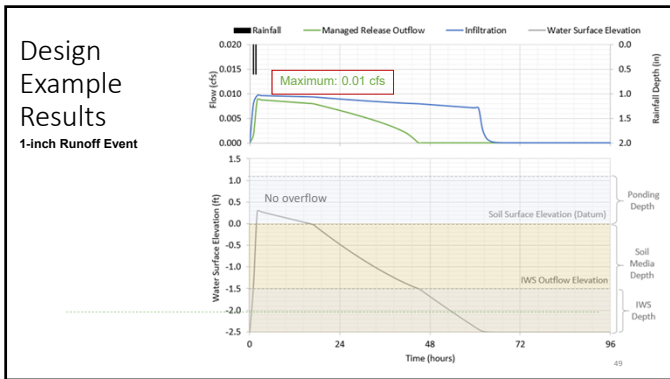
Design Example

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

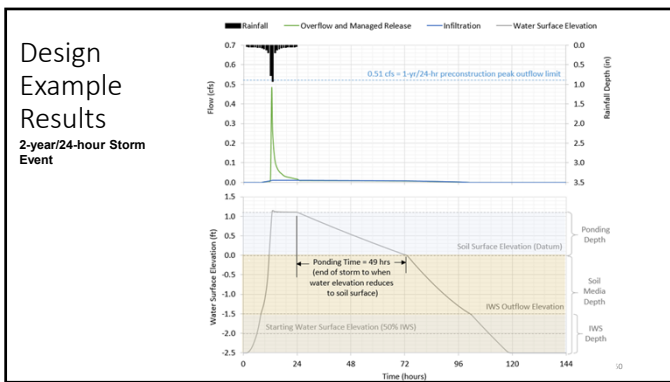


Parameter	Value
BMP footprint area	0.07 ac
Contributing area (all impervious)	0.8 ac
Ponding depth	1.1 ft
Media depth	2.5 ft
IWS depth (included within soil media depth)	1 ft
Infiltration rate	0.1 in/hr
Void space	30%

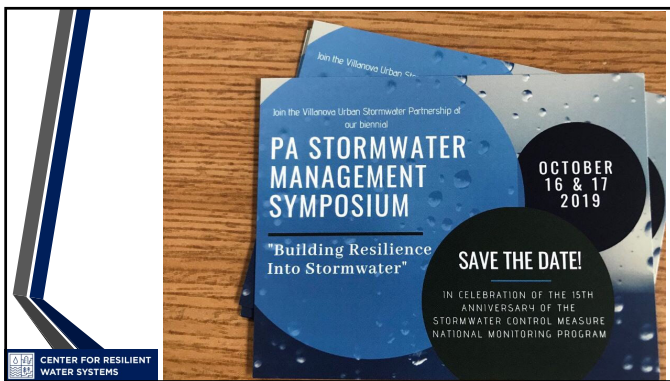
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