green roof hydrology

with Charlie Miller

The Roofmeadow Team

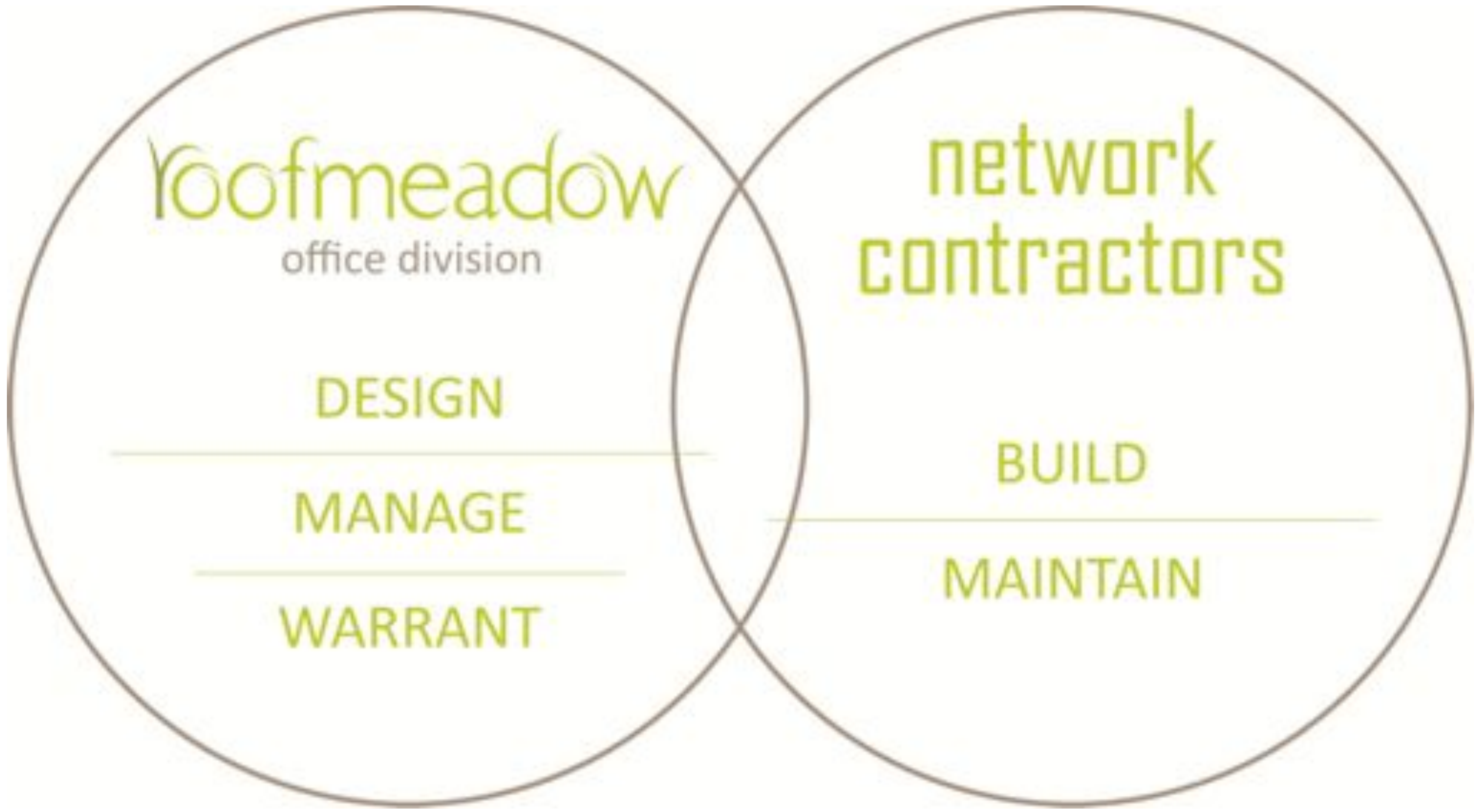
Multidisciplinary firm, since 1997

Engineers | horticulturalists | landscape designers

Equipped to address all aspects of green roof design and management

National network of licensed contractors

Design | Manage | Warrant approach


roofmeadow
office division
DESIGN
MANAGE
WARRANT
network
contractors
BUILD
MAINTAIN

HYDROLOGIC BENEFITS
DRAINAGE LAYERS
DESIGNING FOR SYRACUSE

roofmeadow

HYDROLOGIC BENEFITS

How do green roofs moderate runoff?

Retention (permanent water storage)

Detention (semi-permanent water storage)

Retention

Permanent water storage

Field capacity: 15% by volume

Moisture content at 1/3 bar capillary pressure

Detention

Semi-permanent water storage

1| Delayed release

Maximum water capacity: 25% by volume

Water transpired in warmer months

2| Transient storage

Water stored briefly in pore space: 10%

Runoff discharge follows a first-order discharge rate.

But what is the constant?

Walmart Store #5402

Largest green roof research site in country

3 inches of media

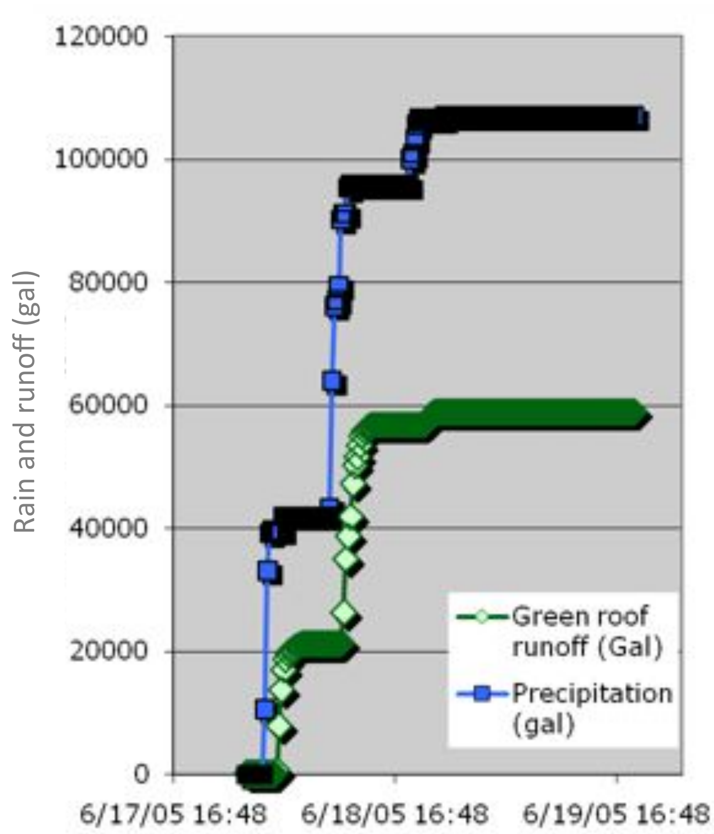
Low-transmissivity drainage layer

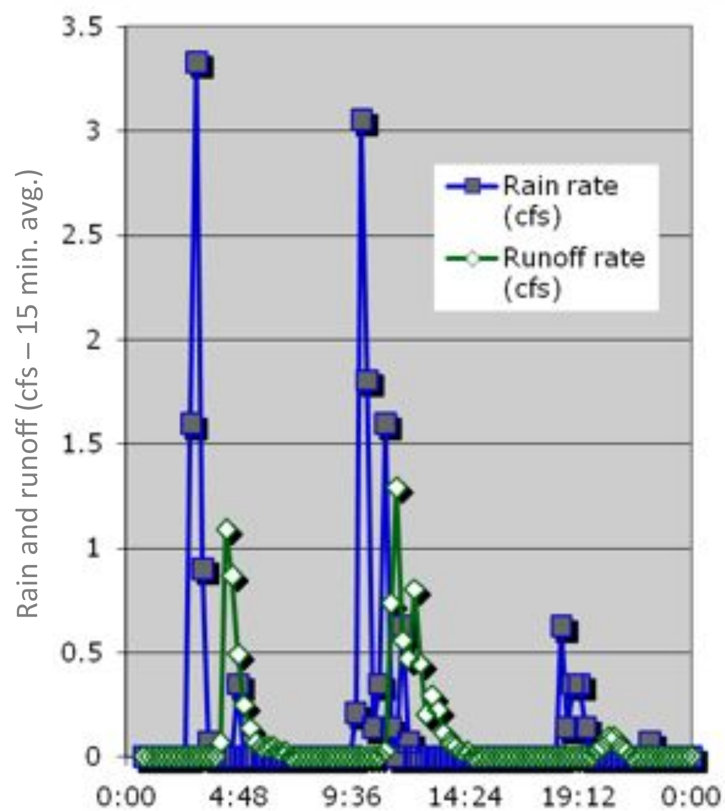
75,000 square foot green roof

Stormwater Performance

Roof performance in **larger storm event** (2.29" precipitation, 1.26" runoff)

Berghage, et al. (2010) (courtesy of Walmart and Pennsylvania State University)

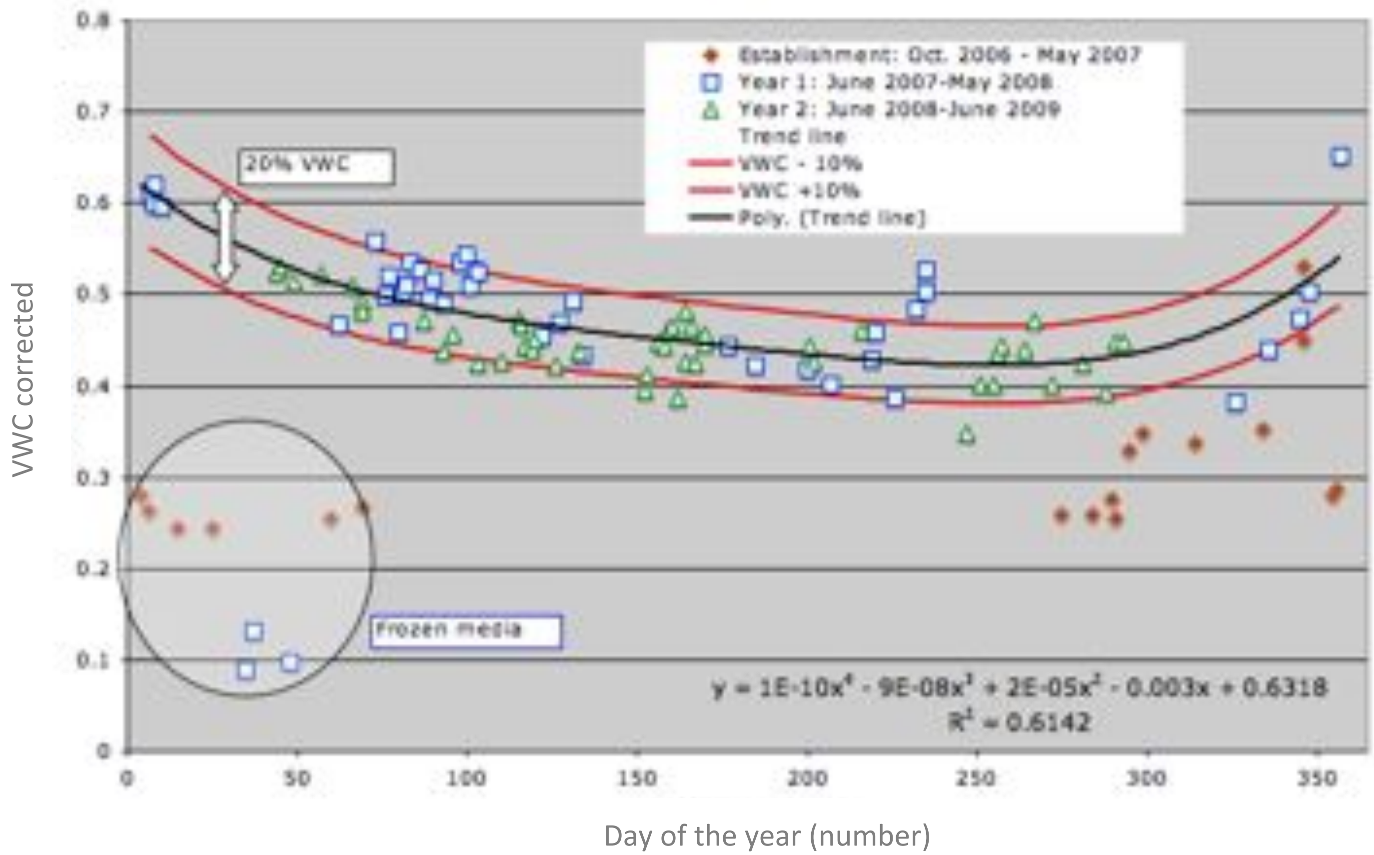




roofmeadow

Volume Retention

Berghage, et al. (2010) (courtesy of Walmart and Pennsylvania State University)

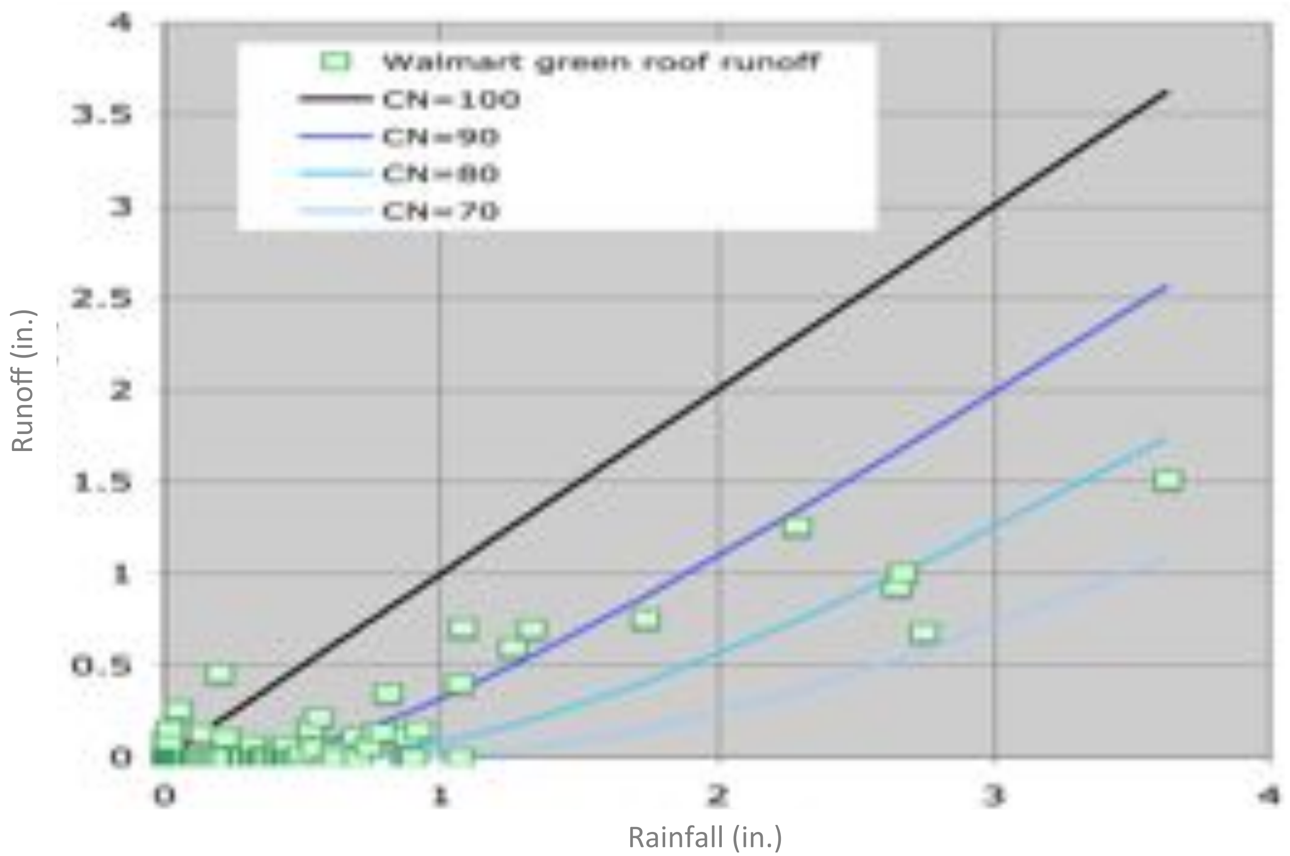


roofmeadow

Curve Number

Berghage, et al. (2010) (courtesy of Walmart and Pennsylvania State University)

Best-Fit CN = 80

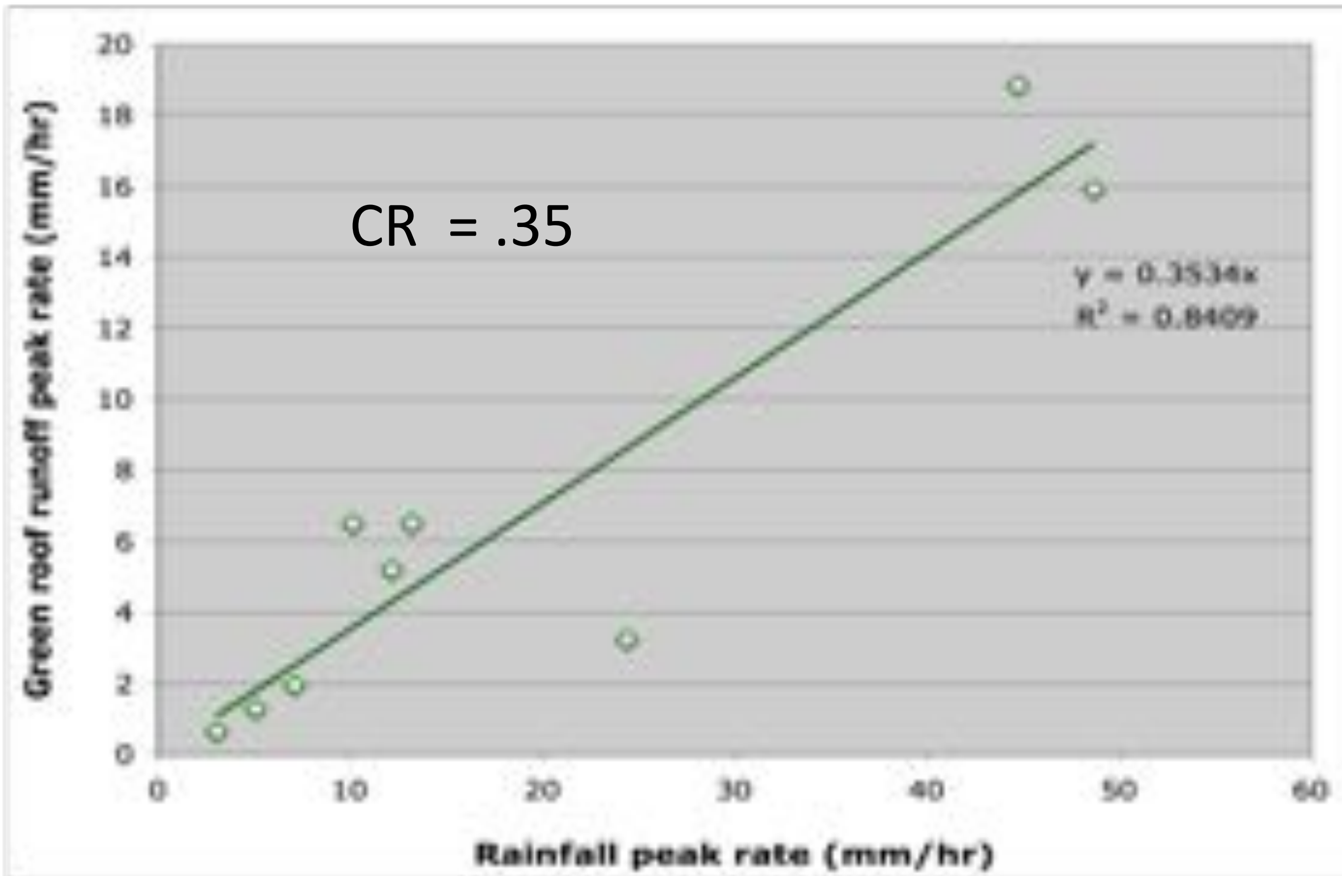


roofmeadow

Runoff Coefficient

Berghage, et al. (2010) (courtesy of Walmart and Pennsylvania State University)

Runoff (in.)



Rainfall (in.)

roofmeadow

Statistical Analysis

10-years of Boston area rainfall data

4 inch thick dual media assembly

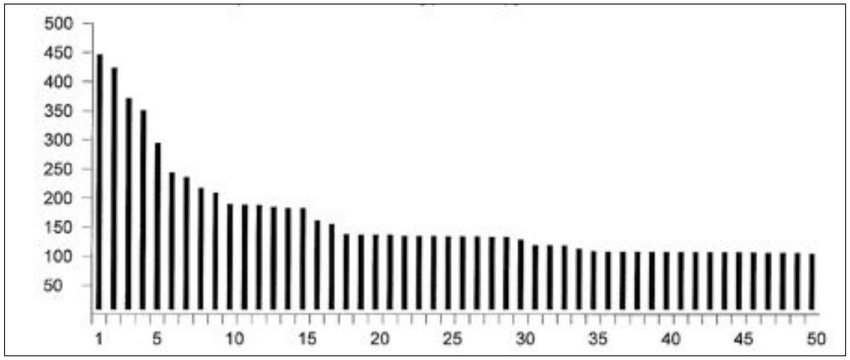
Computer simulation using RWS program

Rational Coefficient

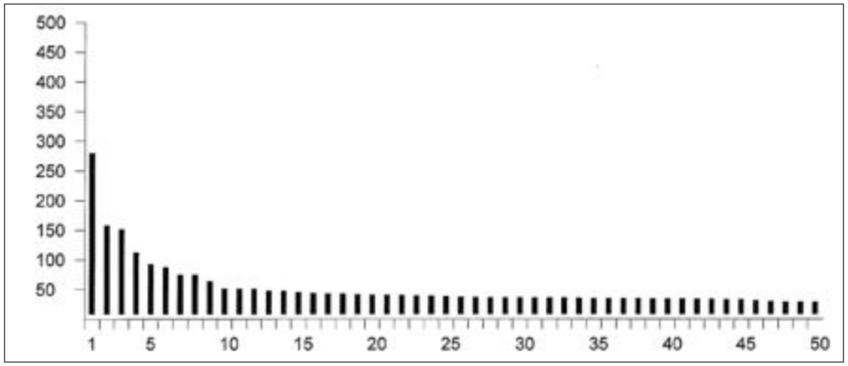
$C_{R_1} = 0.37$

$C_{R_2} = 0.39$

$C_{R_{10}} = 0.42$



Without a green roof

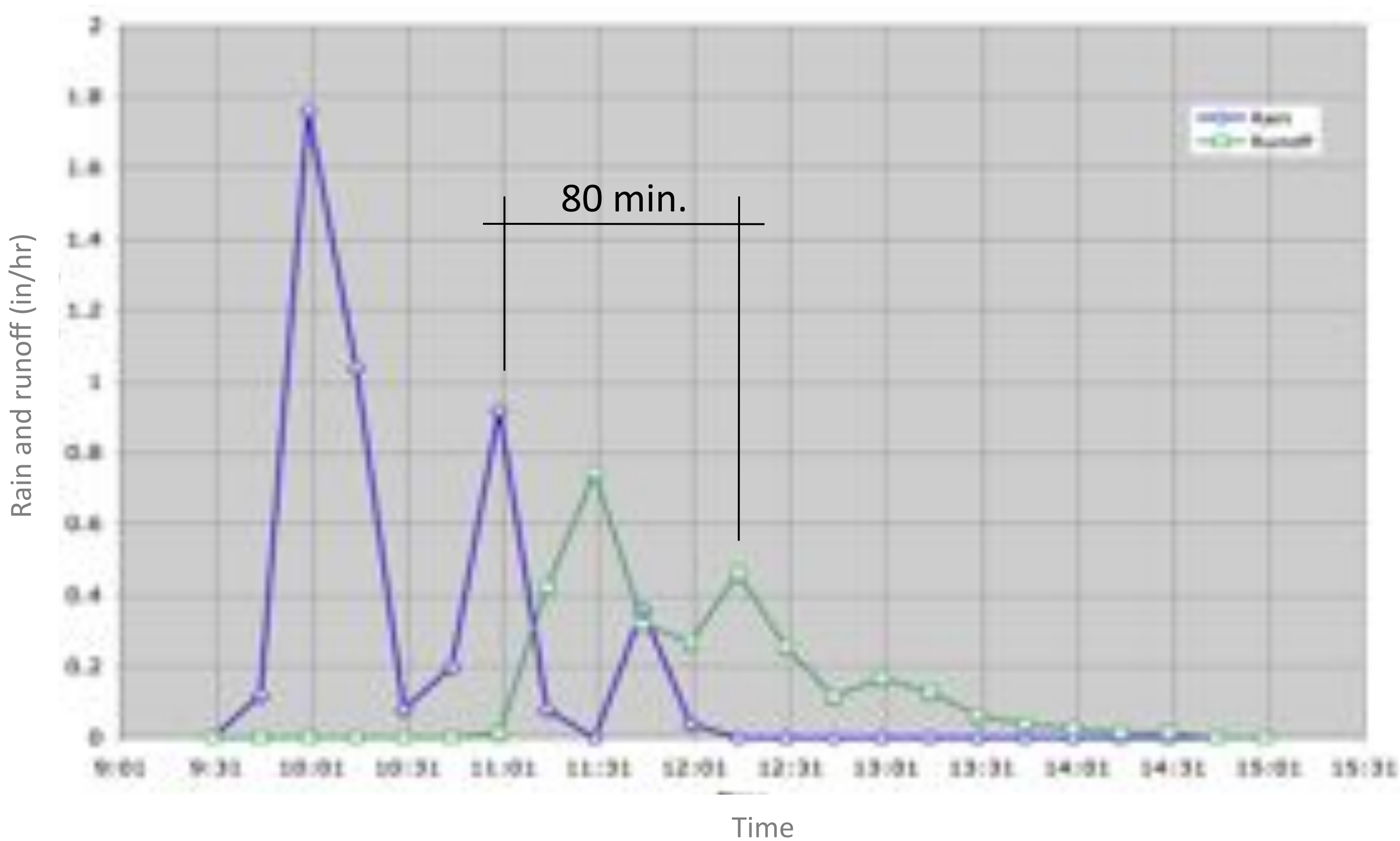


With a 4 inch thick green roof

roofmeadow

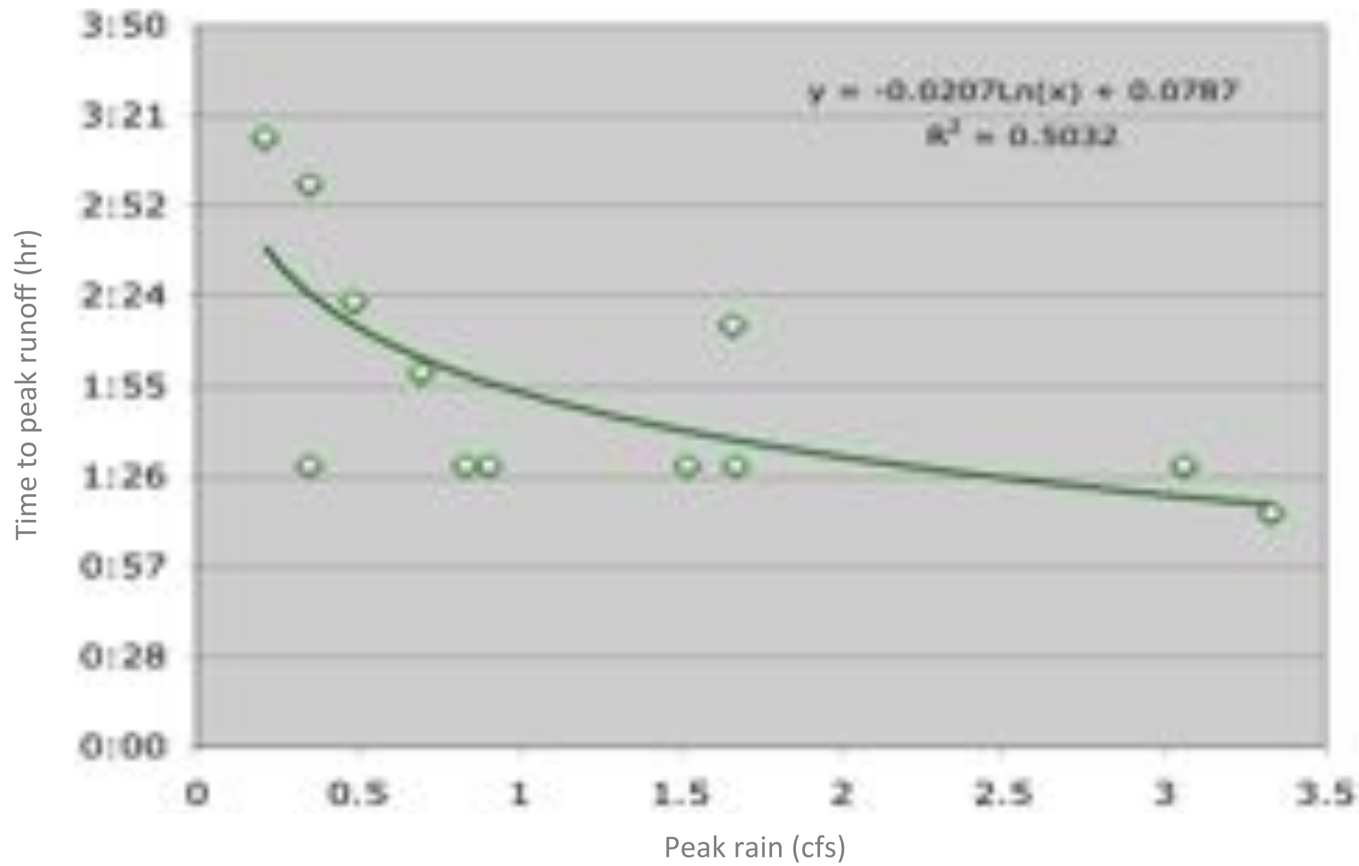
Time to Peak

Berghage, et al. (2010) (courtesy of Walmart and Pennsylvania State University)



Time to Peak

Berghage, et al. (2010) (courtesy of Walmart and Pennsylvania State University)



roofmeadow

Walmart Store #5402
Summary of Results

Initial abstraction:	~0.5 inch
NRCS Curve Number:	~80
Time of concentration:	~100 min

But wait!

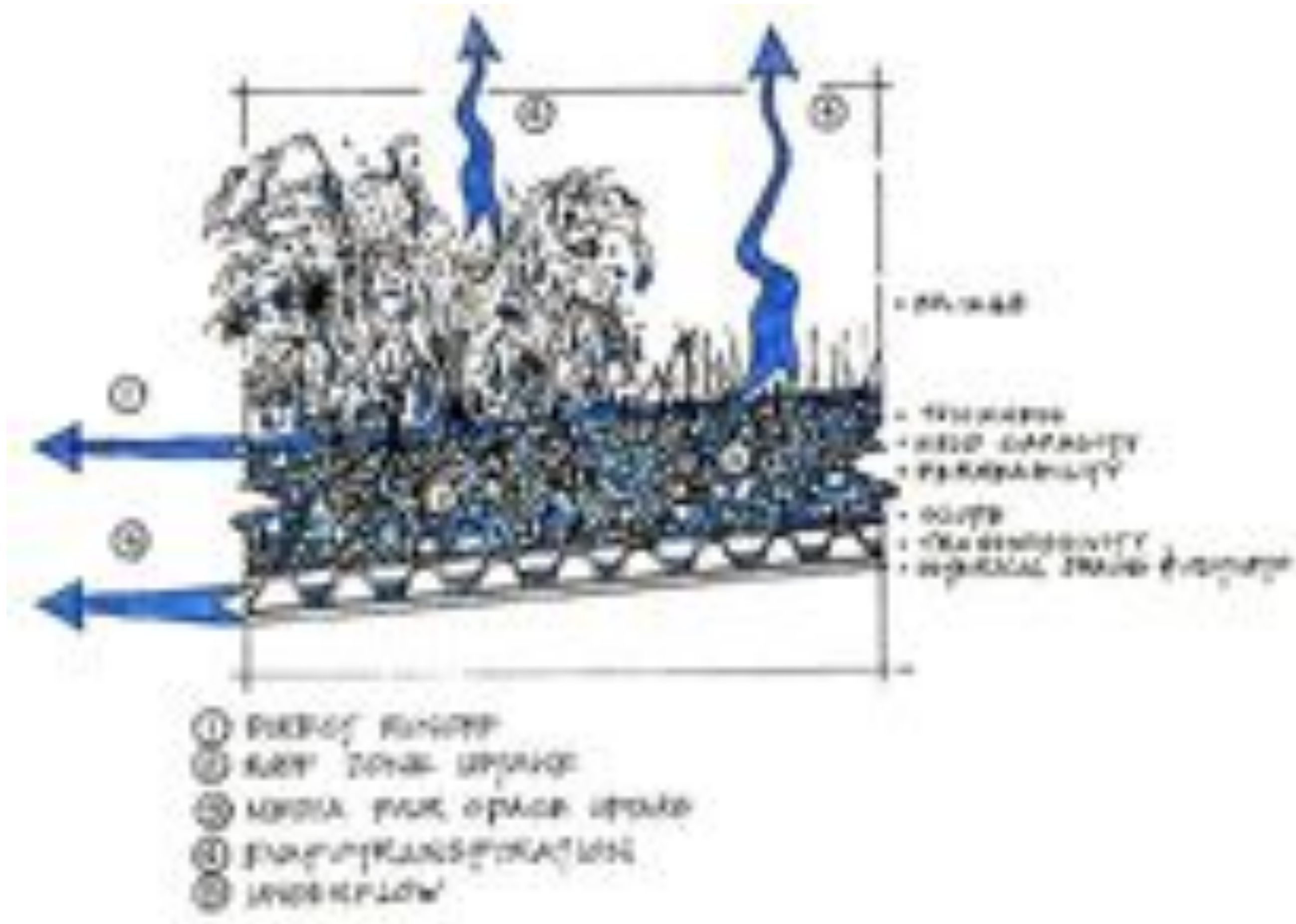
Why didn't previous predictions of runoff rate reductions using TR-20/55 match observations or RWS simulations?

Time of concentration was underestimated because

We are operating under the wrong paradigm!

How could this happen?!

We’ve been looking at only 1/2 of the green roof landscape

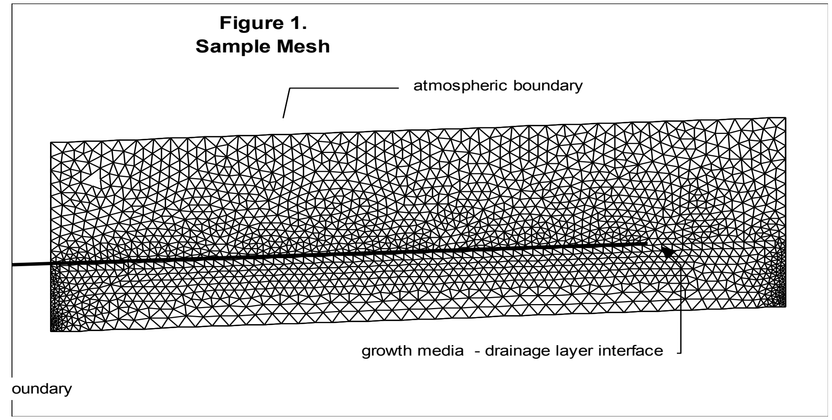


How to Understand Green Roofs

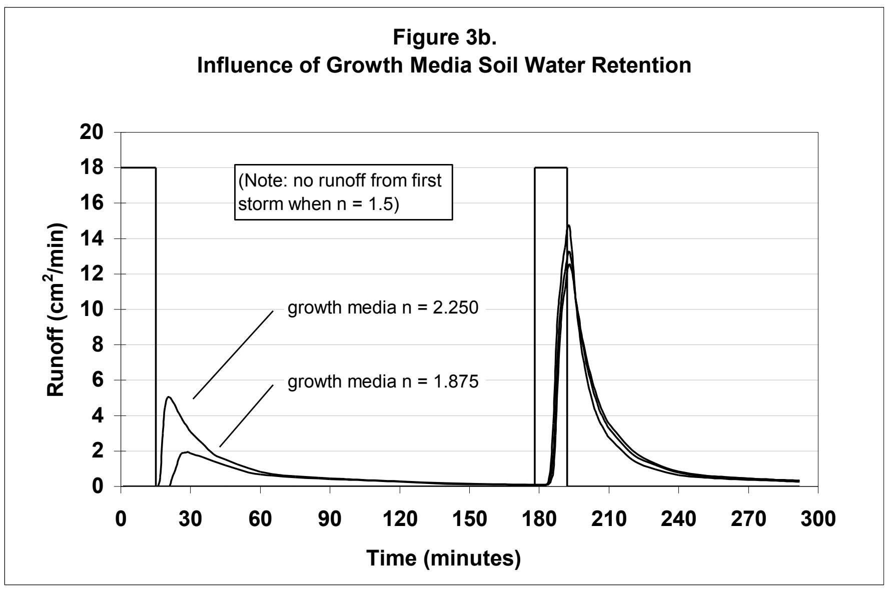
roofmeadow

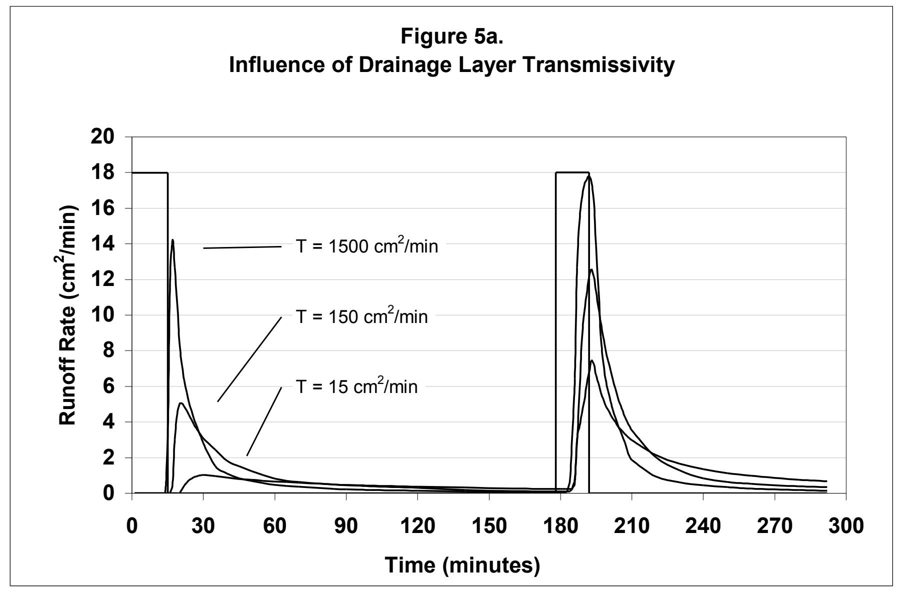
Green Roofs as Shallow Groundwater Systems

Miller (1999), ASCE Seattle



results of finite element analysis





Primary Questions

1| What is the meaning of "infiltration" in green roof modeling?

2| What is the "time of concentration" for green roofs? How do we estimate it?

3| Given the long delays in runoff, is it reasonable to average green roof curve numbers or runoff coefficients with ground landscapes and sub-watersheds?

4| Are existing stormwater runoff models adequate for predicting discharge from green roofs?

Walmart Store #5402
Conclusions

Roof size matters

Flow path length matters

Time of concentration is critical to hydrology

Time of concentration is not well-researched

Thin assemblies can be very effective

Effect of Long Times of Concentration

More efficient retention of rainfall

(media absorption + real-time plant uptake)

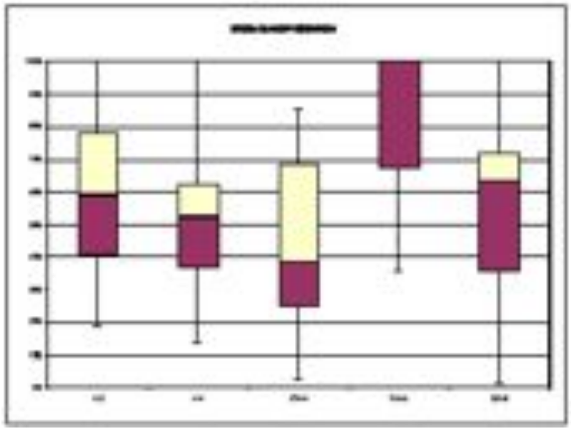
Peak runoff delay

Runoff peak rate reduction

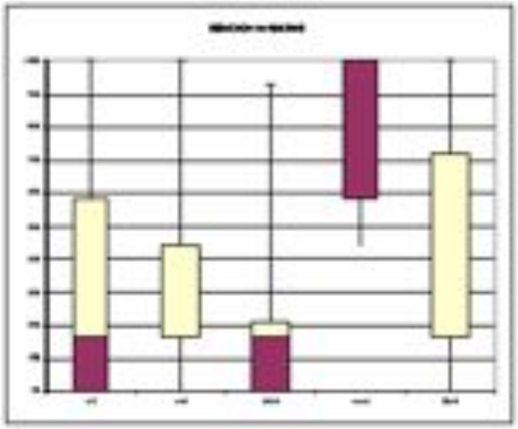
DRAINAGE LAYERS

Factors that Influence Performance

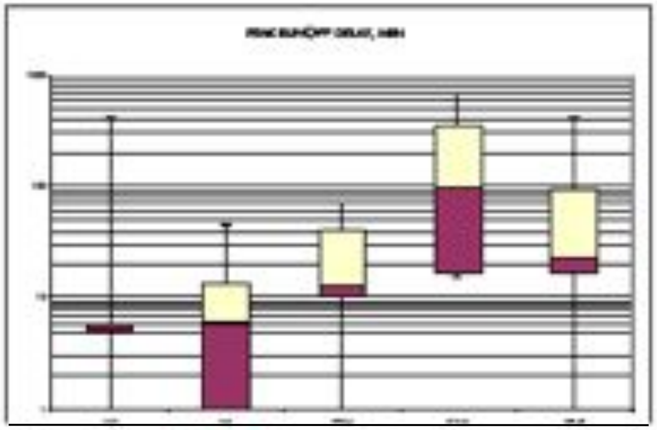
Brian Taylor (2008), ASCE Seattle



Retention



Peak attenuation

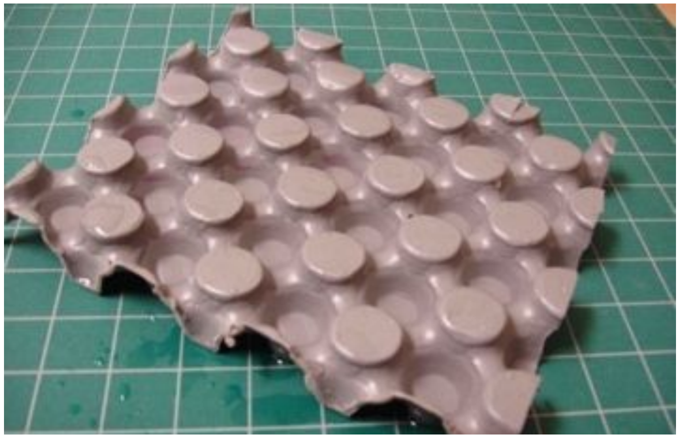


Runoff delay

Synthetic Drainage Layers

Drainage layer has critical influence on performance

Synthetic mats



Reservoir Sheets

Fabric composites

Geocomposite drain sheets

Granular Drainage Layers

Course drainage media under growth media

Distinguishing Characteristics

Horizontal transmissivity **25** to **1,000** times greater than overlying "growth media"

Results in vertical percolation in overlying layers

Rate of water movement off of the roof dependent upon hydraulic properties of drainage layer

Measures of Performance

Tortuosity (unit-less coefficient)

Transmissivity (m^2/s): flow potential parallel to roof [ASTM D4716]

Vertical Percolation Potential (gpm/sf): flow potential perpendicular to roof [ASTM D4491]

Transmissivity for Simple Drainage Layers

Intrinsic property of the layer

Measures the in-plane flow capacity at laminar or near-laminar flow conditions

ASTM D4716 and ASTM E2396

Typical geocomposite drain sheet:	**.050 - .200**	m^2/s
Typical 2 inch granular drainage layer:	**.001 - .004**	m^2/s
Typical synthetic mat (foam or fabric):	**.002 - .008**	m^2/s

Transmissivity of 0.1 m^2/s associated with flow of 10 gpm/ft with roof gradient of $i = 0.2$

Low-Head Permeability Apparatus

[ASTM E2396]

For coarse granular media

i = 0.04 - 0.30

Typical K values

- 25 - 100 in/min
- 1 - 4 cm/sec

DESIGNING FOR SYRACUSE

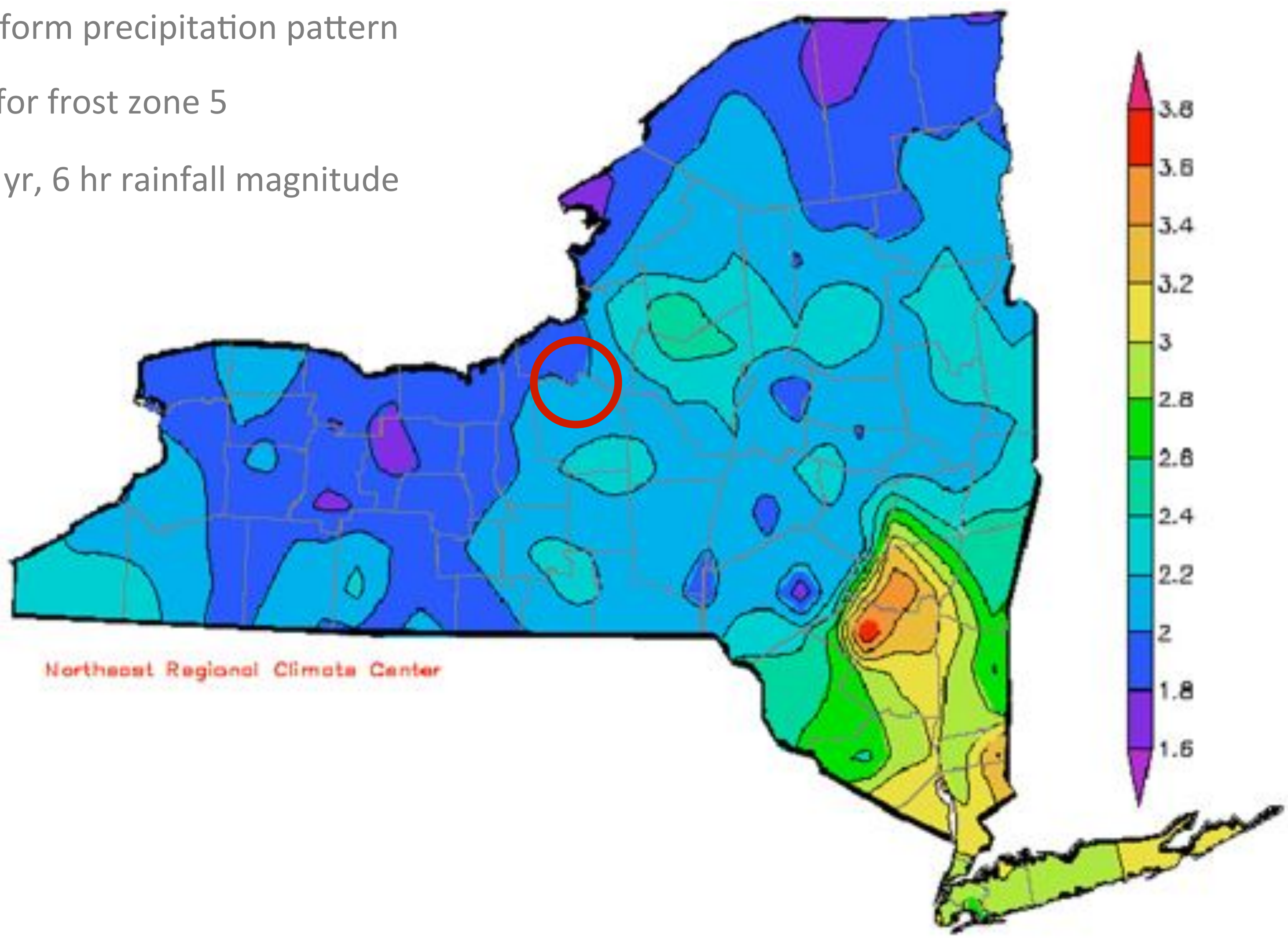
roofmeadow

Syracuse, NY

Remarkably uniform precipitation pattern

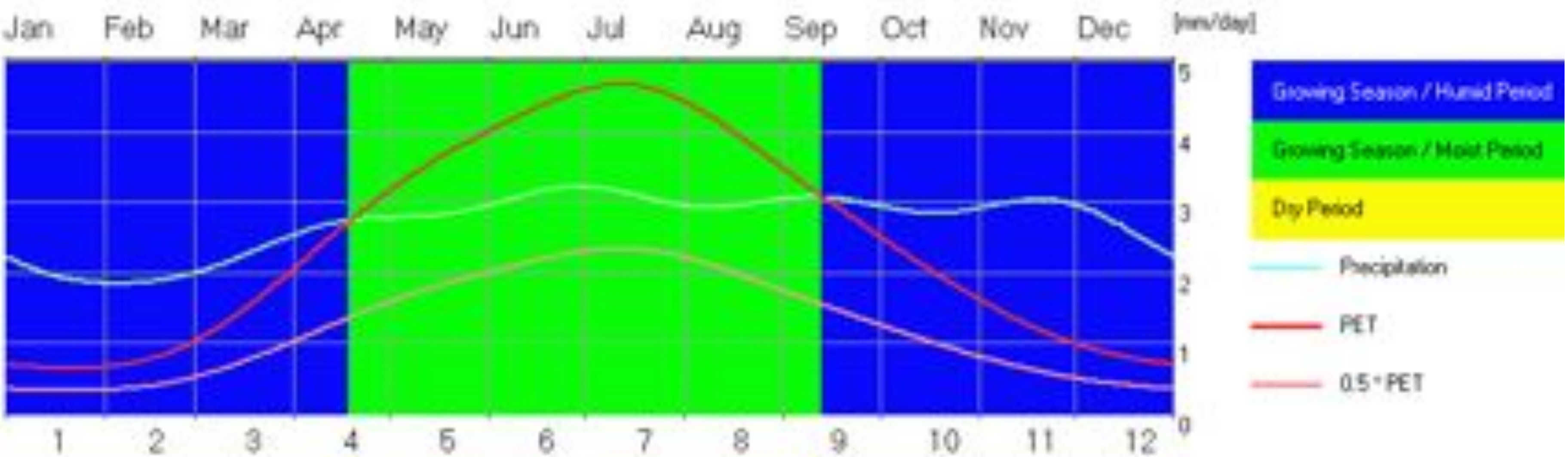
Plant selection for frost zone 5

Map showing 5 yr, 6 hr rainfall magnitude



Climate Analysis

Aridity index (summer rainfall/PET):	0.6
Frost zone:	5
Heat zone:	3
Annual rainfall (inches):	39
Storm intensity (5 yr/6 yr) (inches):	2



Load Implications

Typical green roof media wet density: 75-80 pcf

Green roof media moisture retention: 35-40% (by volume)

Dry Density pcf	Wet Density pcf	Thickness in	System Dry Weight Psf	System Wet Weight psf	Relative System Cost
55	75	3	15	22	1
45	65	3	13	20	1.2
35	55	3	10 *	17	1.4

* may not satisfy wind-scour guidelines for exposed roofs

Load Evaluation

Critical for retrofit projects

Be sure to include:

- Wet + compressed soil
- Stored free water
- Mature plants
- Miscellaneous fabrics

No stable media is less dense than 50 PCF

Do the math! [ASTM E2397]

Predicting Performance in Syracuse

Four green roof types simulated

Used 10 years of rainfall from Syracuse records (1984-1993, 15-minute, NOAA NNDC)

Assembly types evaluated had no high-efficiency synthetic drainage layer (drainage media only)

Assemblies ranged in thickness between 3-6 inches

Statistical Analysis

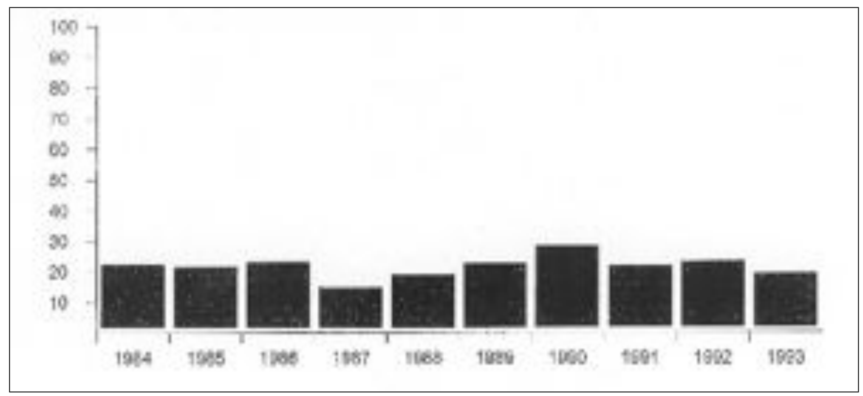
For 10 years of local Syracuse rainfall data

3-inch simple green roof

Essential information for design of rainwater harvesting systems

Average annual rainfall: 25%

- Winter: 37%
- Spring: 21%
- Summer: 17%
- Fall: 28%



Annual runoff / annual rainfall

Statistical Analysis

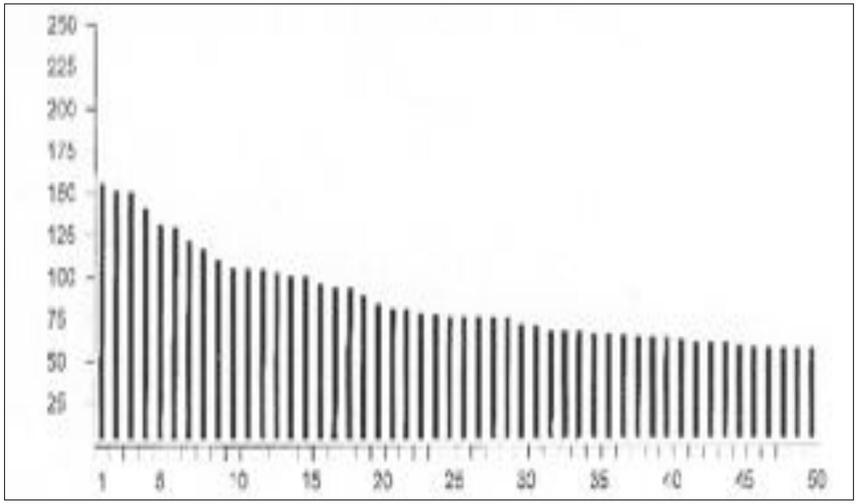
50 largest runoff events

Rational peak rate runoff coefficient

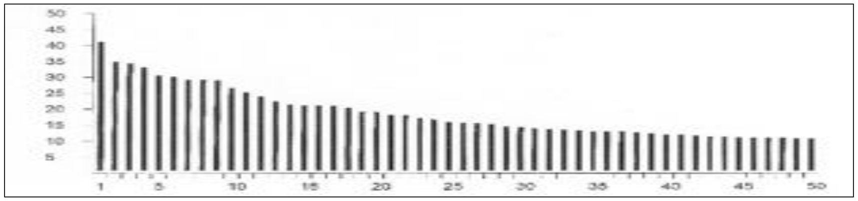
C_1 = 0.18

C_2 = 0.20

C_5 = 0.20



Without a green roof



With a 3” green roof

roofmeadow

Designing Around Local Rainfall Patterns

Runoff management

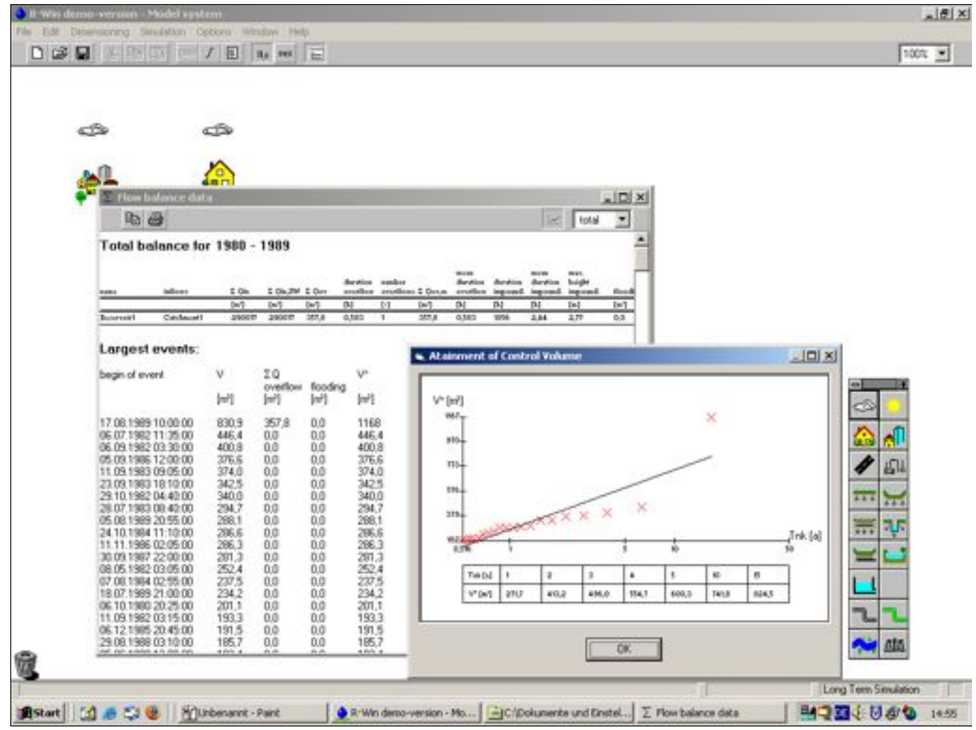
Long-duration continuous simulations

Most reliable estimates of performance

Reflects local climatic conditions

Average “antecedent” moisture conditions

Isolates seasonal influences (i.e., runoff/ rainfall ratios)



Conclusions

Very little improvement in performance with thicker profiles (**recommend no more than 3"**)

Rational Method Peak Rate Coefficient less than **0.25** for 5-year frequency event

Runoff volume ratio less than **30%** for all cases

Appropriate designs should include low-transmissivity drainage layers

Contact Us

w | www.roofmeadow.com

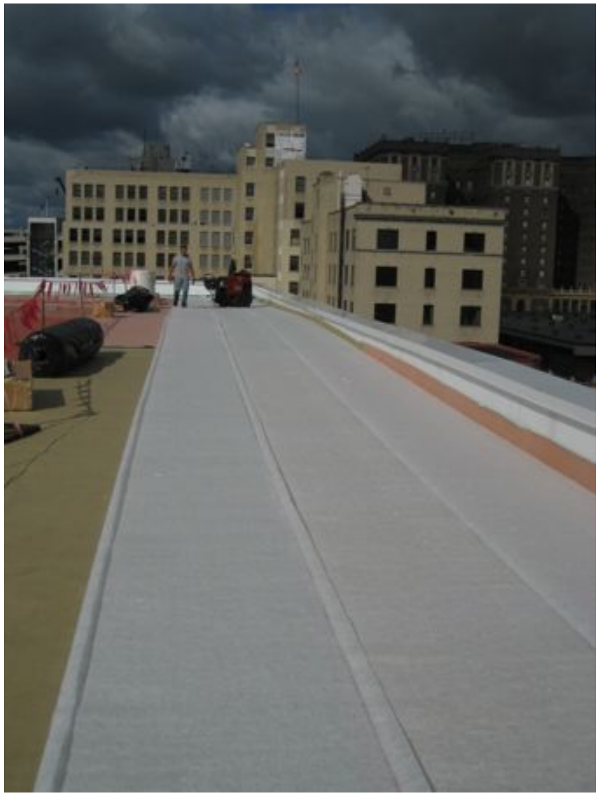
e | info@roofmeadow.com

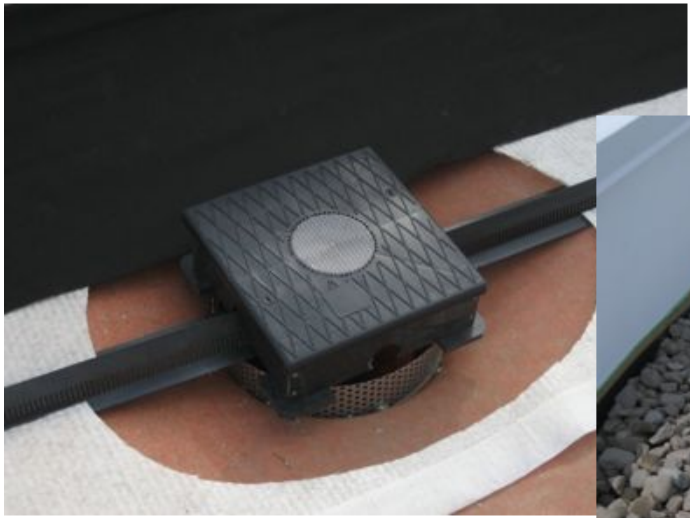
p | 215.247.8784

f | 215.247.4659

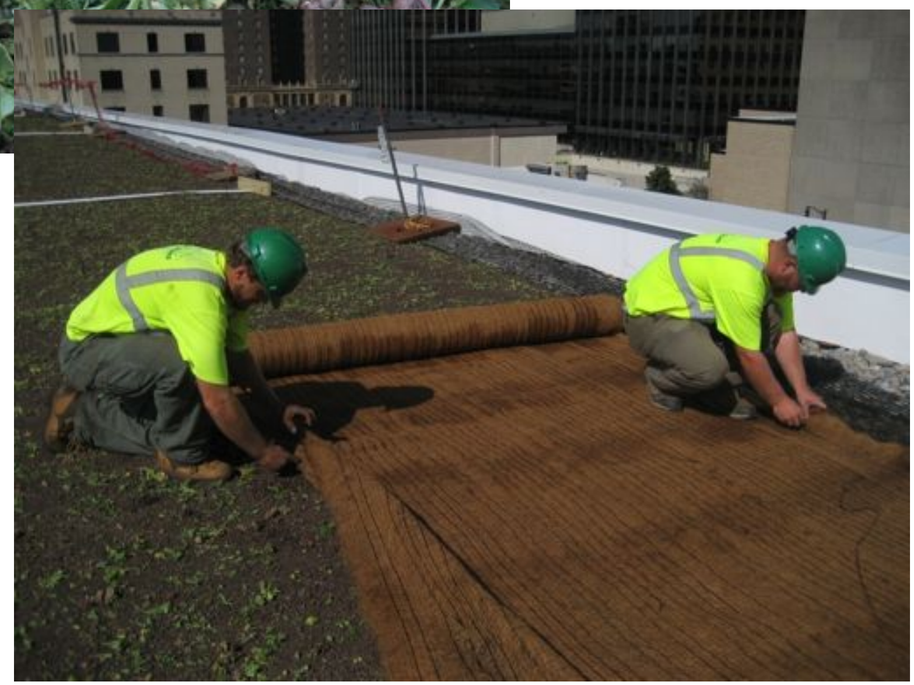
Blog, Twitter, Facebook

Transformation at the On Center





roofmeadow



Contact Us

w | www.roofmeadow.com

e | info@roofmeadow.com

p | 215.247.8784

f | 215.247.4659

Blog, Twitter, Facebook

Material Certification

Roofmeadow certified components

Rigorous performance testing

Best value

Guaranteed compatibility with waterproofing

Long term warranty coverage

Our seal of approval is your piece of mind.

Representative Projects

Chicago City Hall

Brooklyn Botanical Garden

Queens Botanical Gardens

Barnes Museum

Lincoln Park Children's Zoo

PECO Headquarters

Cincinnati Museum Center

Los Angelus Museum of the Holocaust

O'Hare International Airport, North Tower

Baltimore Convention Center

Asbury Woods Nature Center

Kansas City Central Library

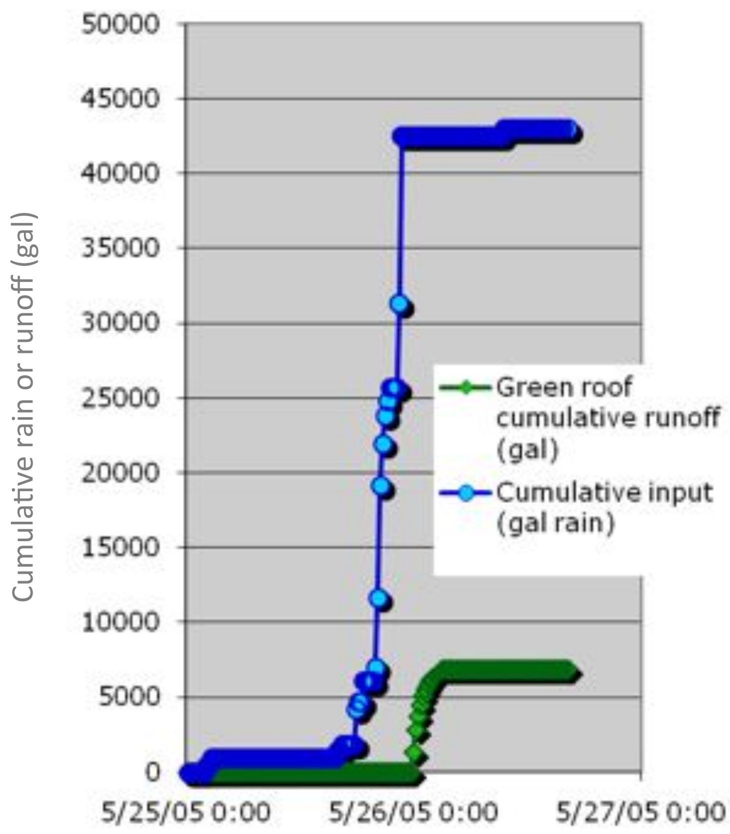
Boston World Trade Center, Podium Building

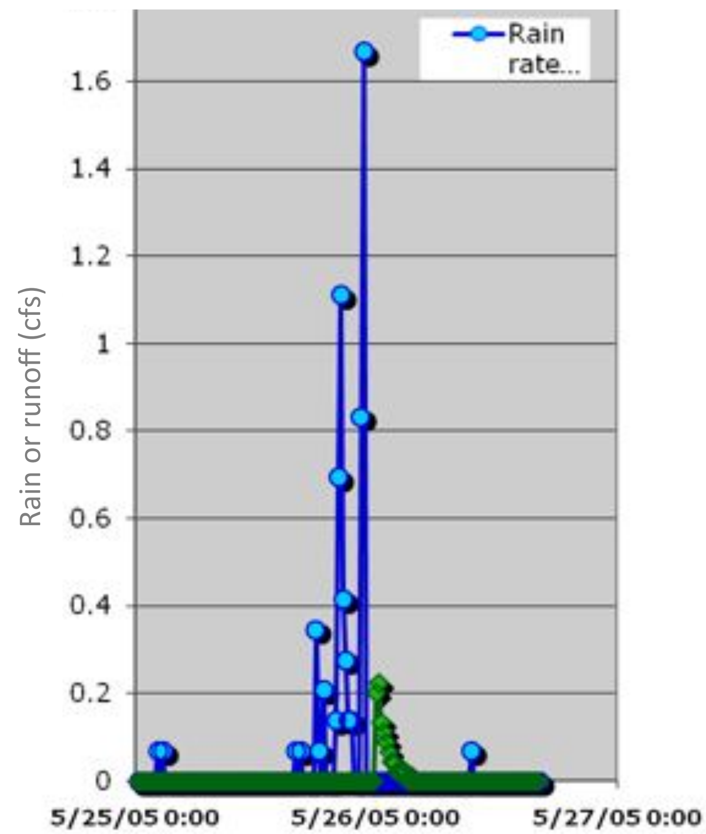
Life Expression Wellness Center

Stormwater Performance

Roof performance in **typical storm event** (0.92" precipitation, 0.15" runoff)

Berghage, et al. (2010) (courtesy of Walmart and Pennsylvania State University)





rootmeadow

A New Vocabulary

For saturated and unsaturated porous media flow in green roofs

Transmissivity

Permeability

Percolation

Tortuosity

Residence time / half-life

Water-holding capacity

Drainage Layer Detention Volume

Moisture Holding Capacity

ASTM E2399 and E2397

Growth media:	30 - 45% of thickness
Reservoir sheet:	10 - 25% of thickness
Granular drainage layer:	5 - 15% of thickness
Synthetic mat*:	5 - 50% of thickness

* Typically only ¼" thick