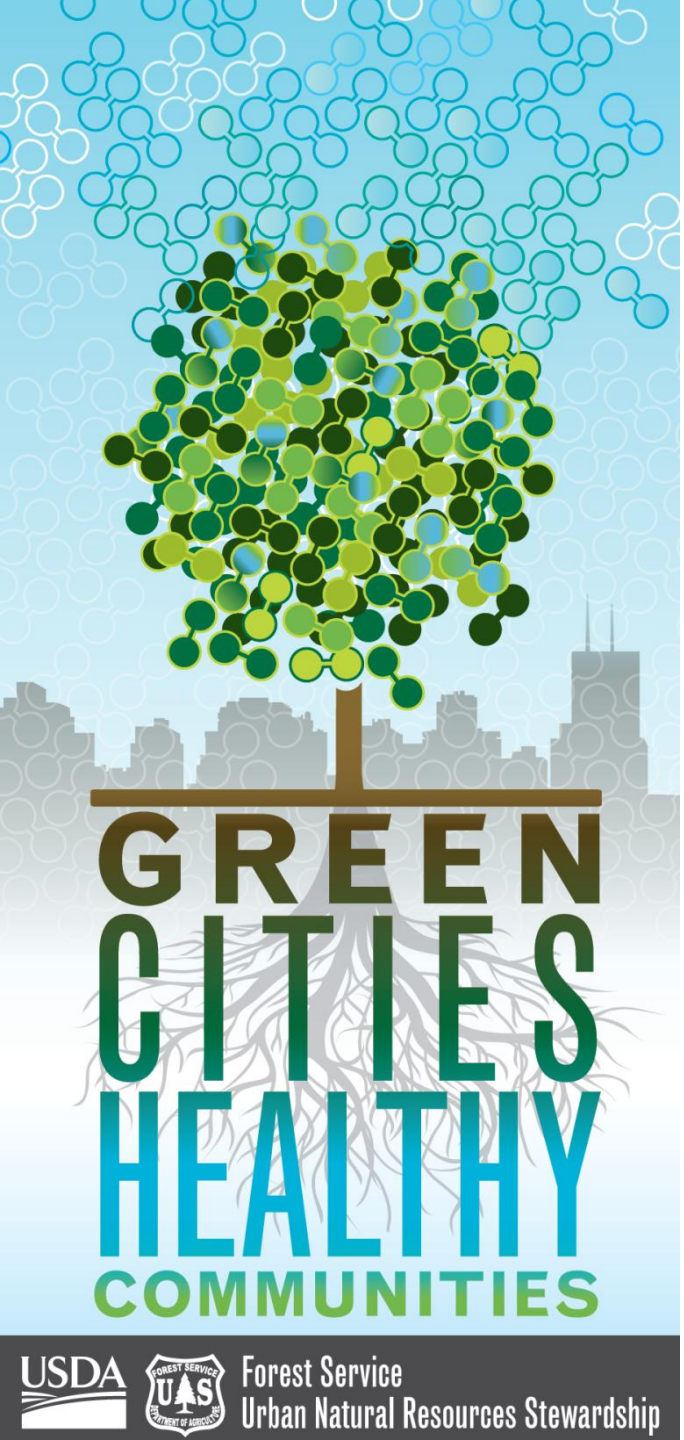

USDA Forest Service

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Quantifying Rainfall Interception in the Urban Canopy

Jon Hathaway

Assistant Professor

University of Tennessee

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Rainfall Interception of Urban Trees in the Knoxville Area

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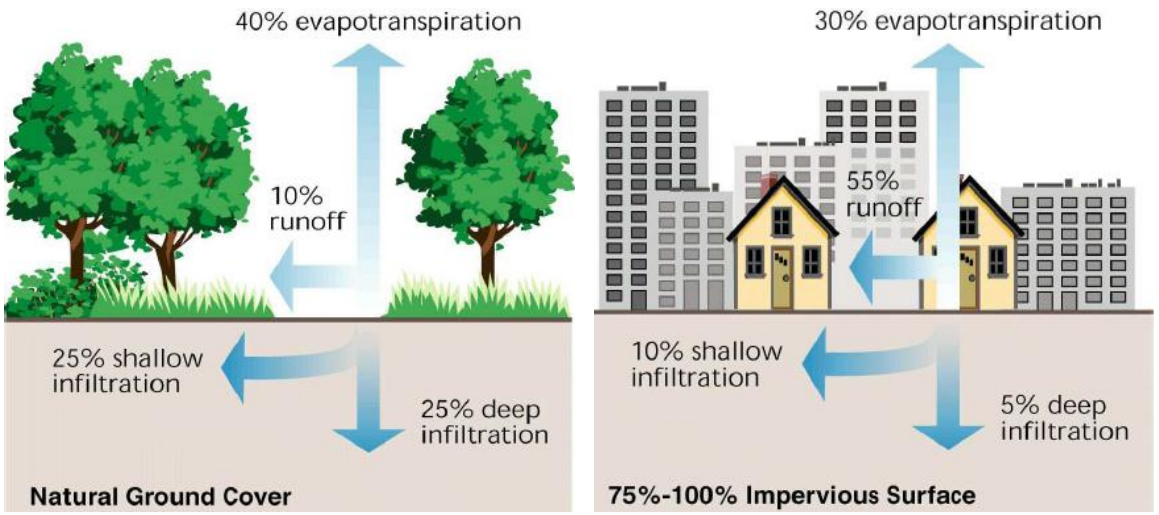
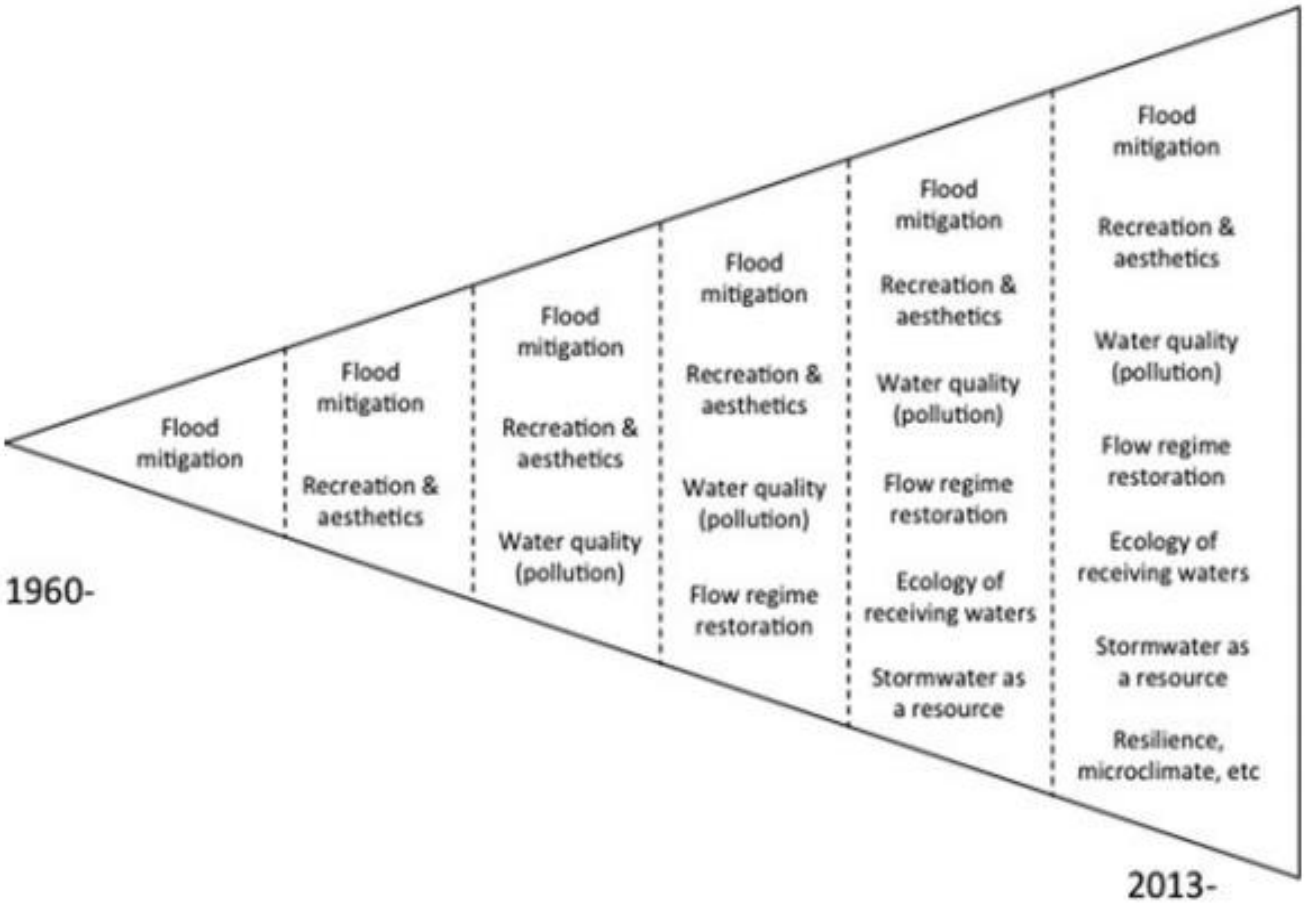
THE UNIVERSITY OF TENNESSEE KNOXVILLE

Urban Stormwater Challenges



- Impervious surfaces limit infiltration, increase runoff quantity delivered to receiving waters, leading to degraded stream conditions
- Pollutants associated with urban areas (sediment, nutrients, heavy metals) impact chemistry and aquatic ecosystems of receiving waters

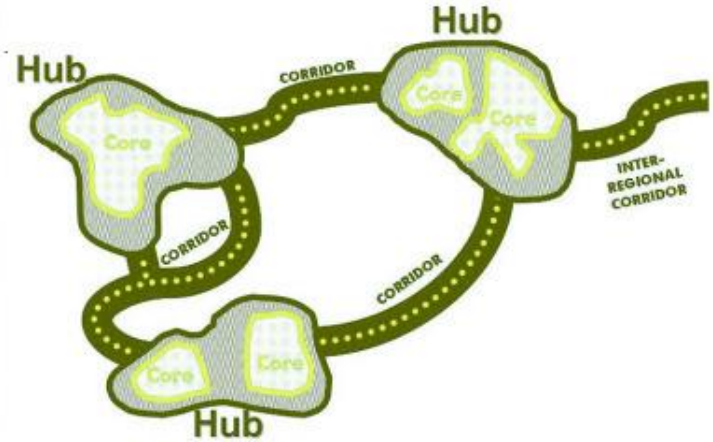
Evolution of Stormwater Management



Fletcher et al., 2015

- **Stormwater Control Measures (SCMs)**
  - "techniques, measures, or structural controls used…to manage the quantity and improve the quality of stormwater runoff" (NRC, 2009)

What is Green Infrastructure?!?

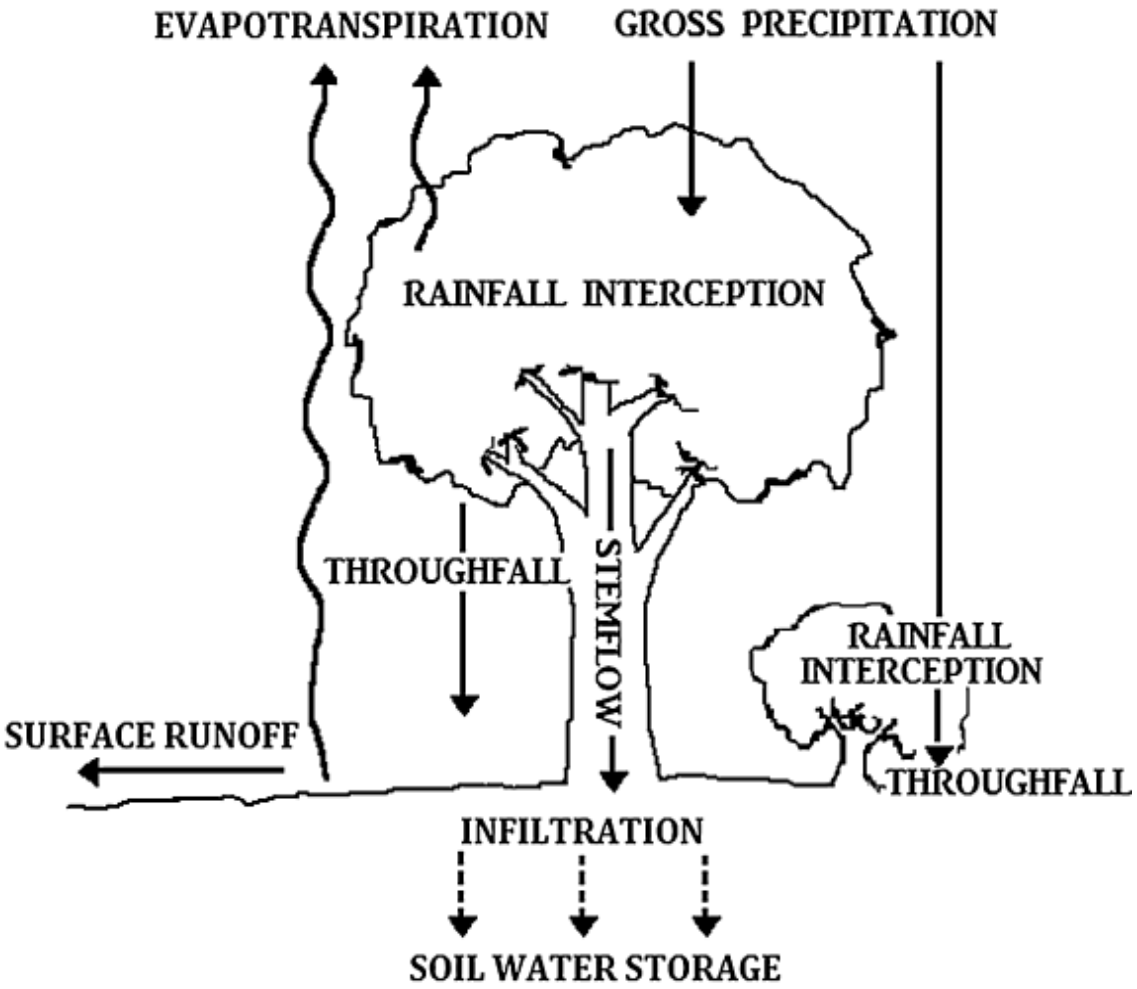


Newcastle University - http://2014-2015.nclurbandesign.org/tag/green-infrastructure/

- With a green infrastructure strategy, communities work to preserve and connect open spaces, watersheds, wildlife habitats, parks, and other critical landscapes (ESRI)

Urban Trees: Stormwater Benefits

- **Hydrology**
  - Interception
  - Transpiration
  - Infiltration
- **Water Quality**
  - Linked to N and P reduction
  - Limited research

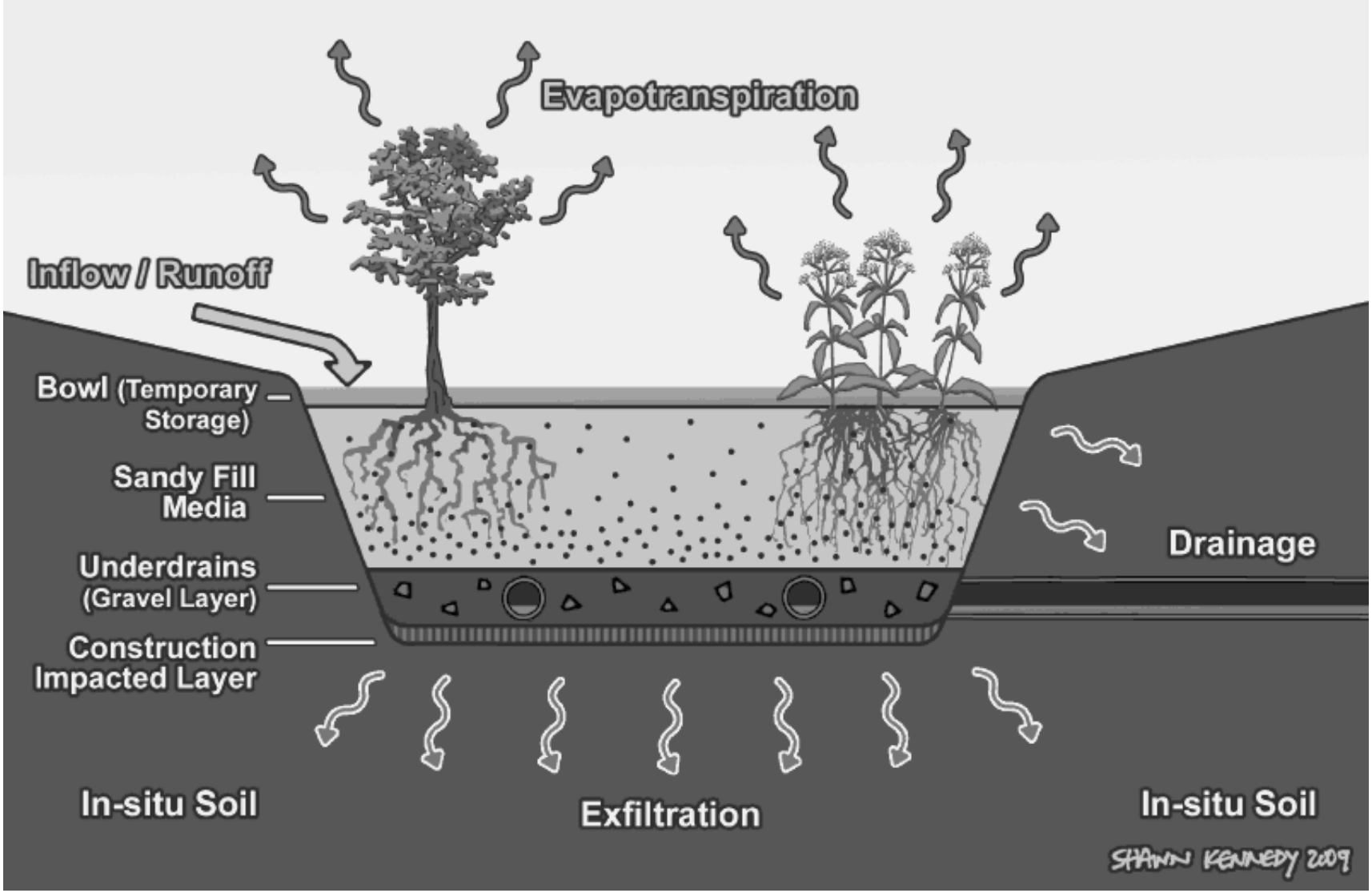


Inkilainen, E. N. M. et al. (2013)

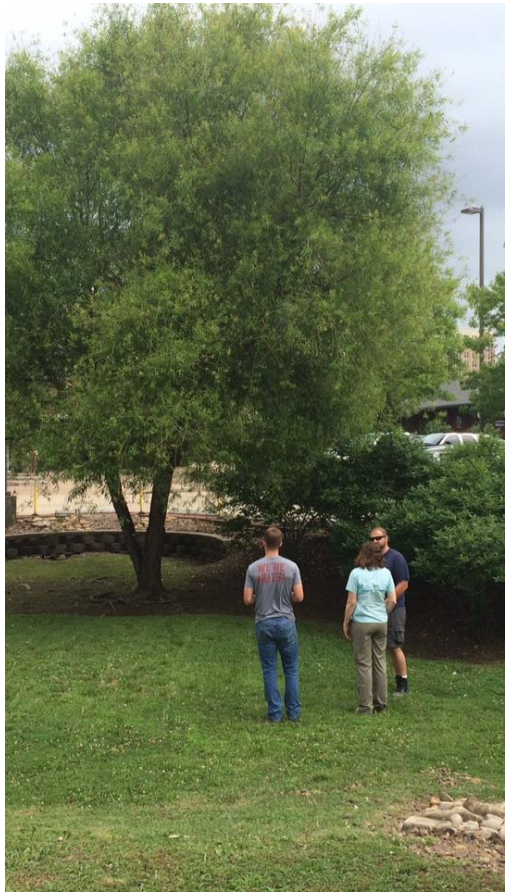
Green Infrastructure

- NUCFAC
  - National Urban and Community Forestry Advisory Council
- Tree function in bioretention cells
  - Field survey
  - Laboratory study
  - Full scale system monitoring

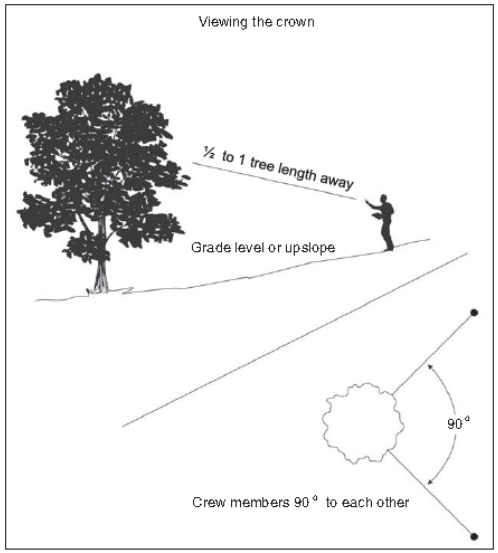
Bioretention Practice: Overview



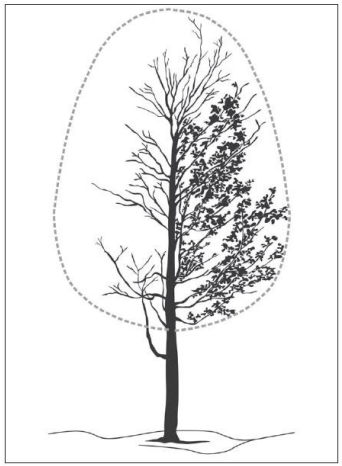
Field Survey



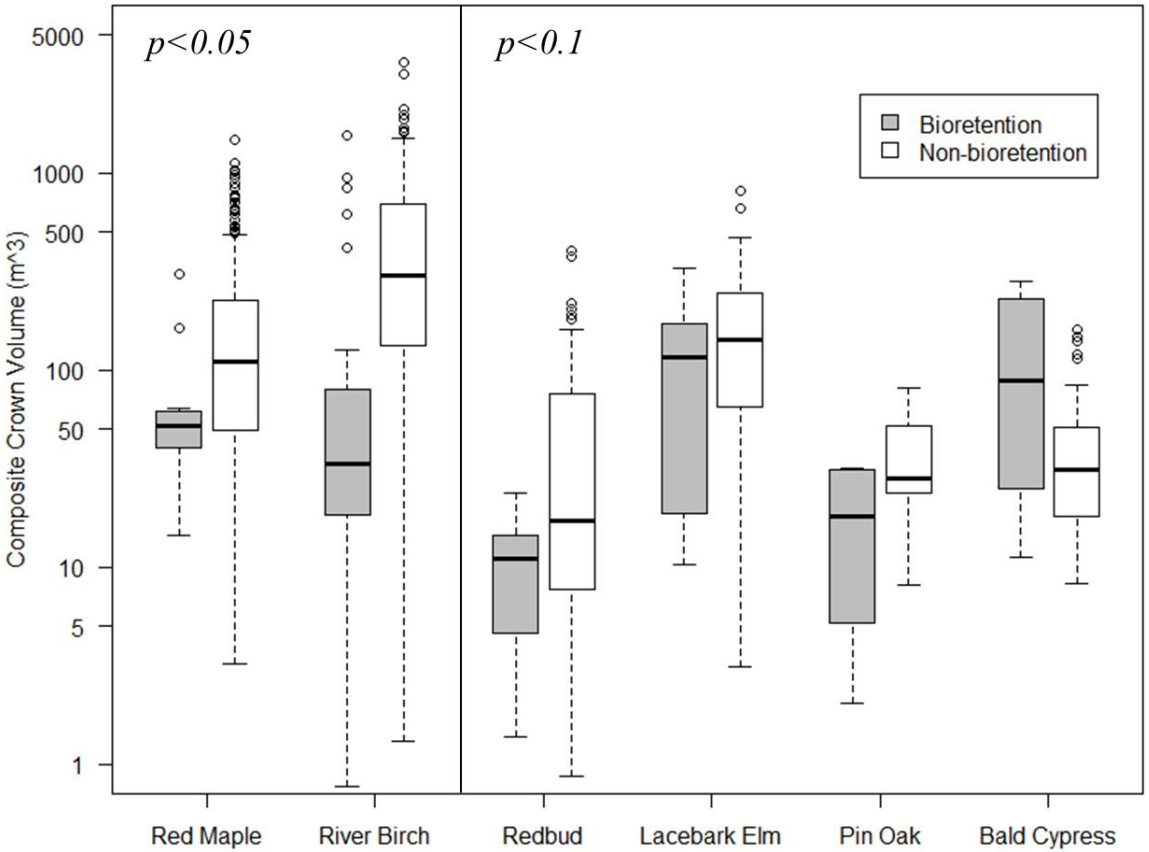
Tree Health in Bioretention



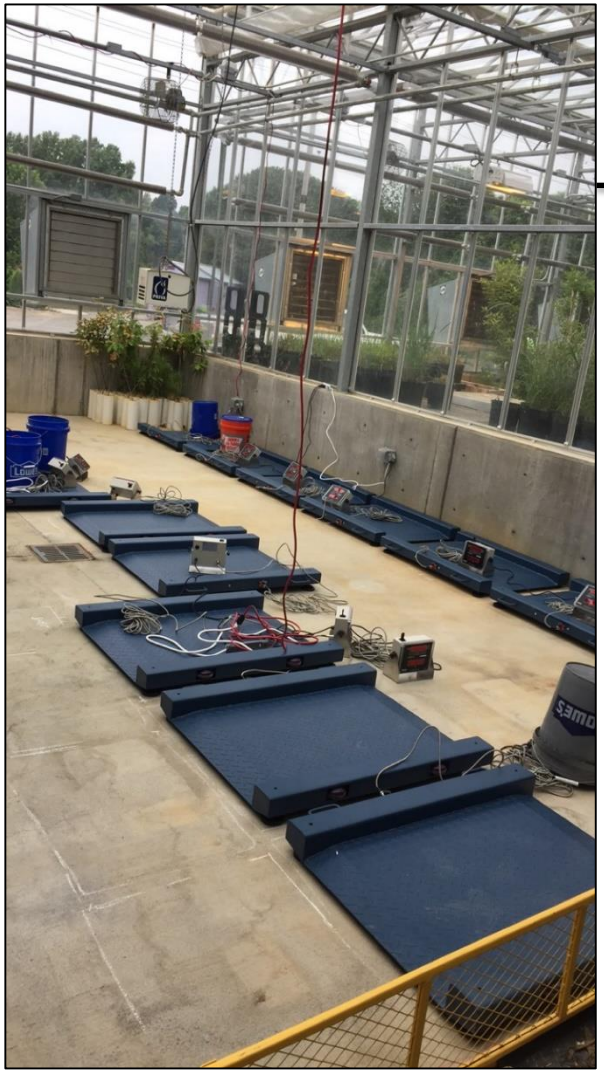
Rating Crown Condition Indicators



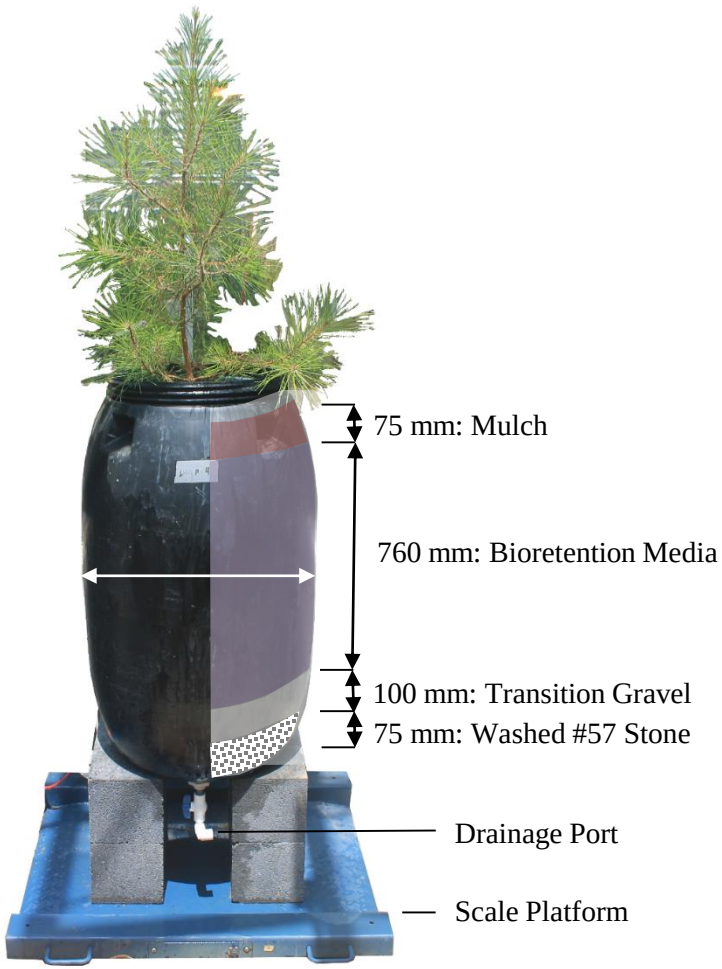
Crown Density

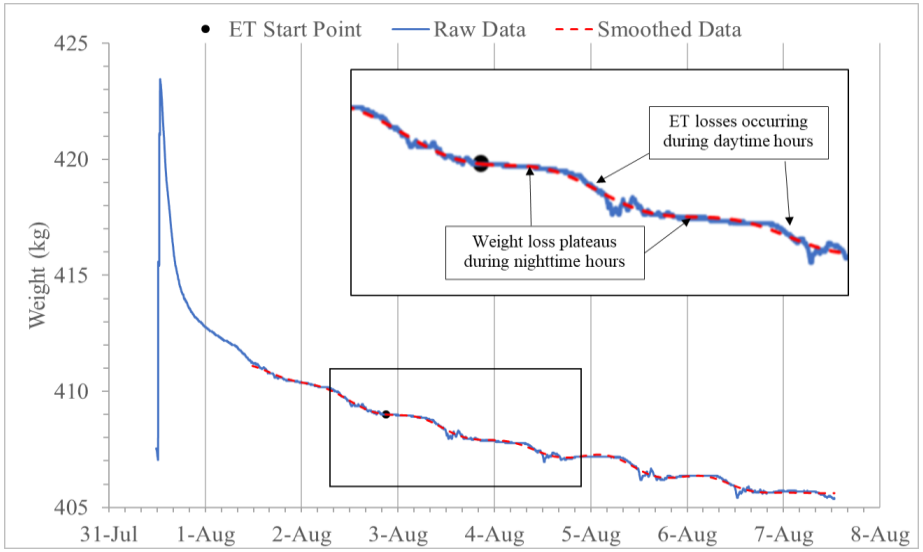


Greenhouse Study



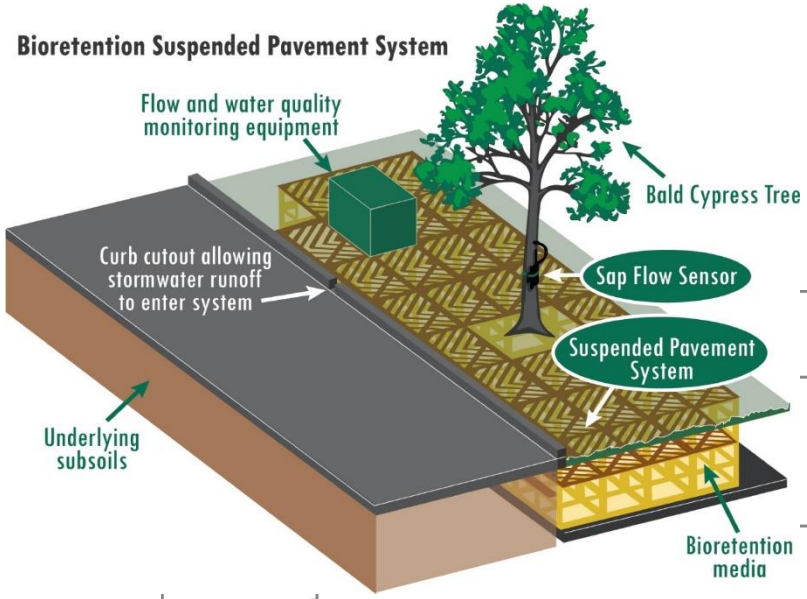
Evapotranspiration

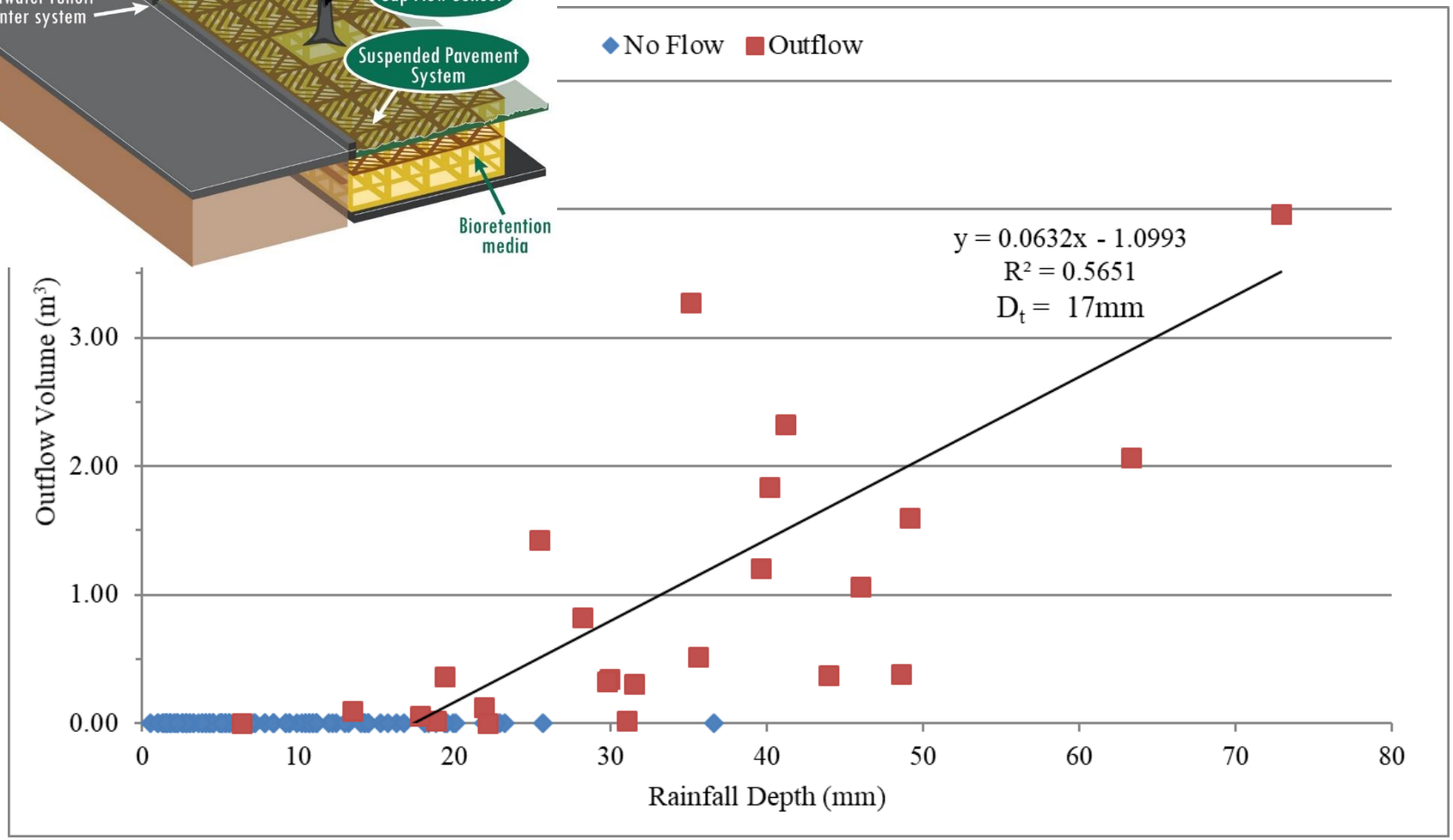




Treatment	Mean ET Rate ±SE (mm d^{-1})
Nonvegetated	2.01±0.10[A]
Loblolly Pine	2.21±0.12[B]
Pin Oak	2.19±0.08[B]
Red Maple	3.22±0.20[C]

Field Scale Study

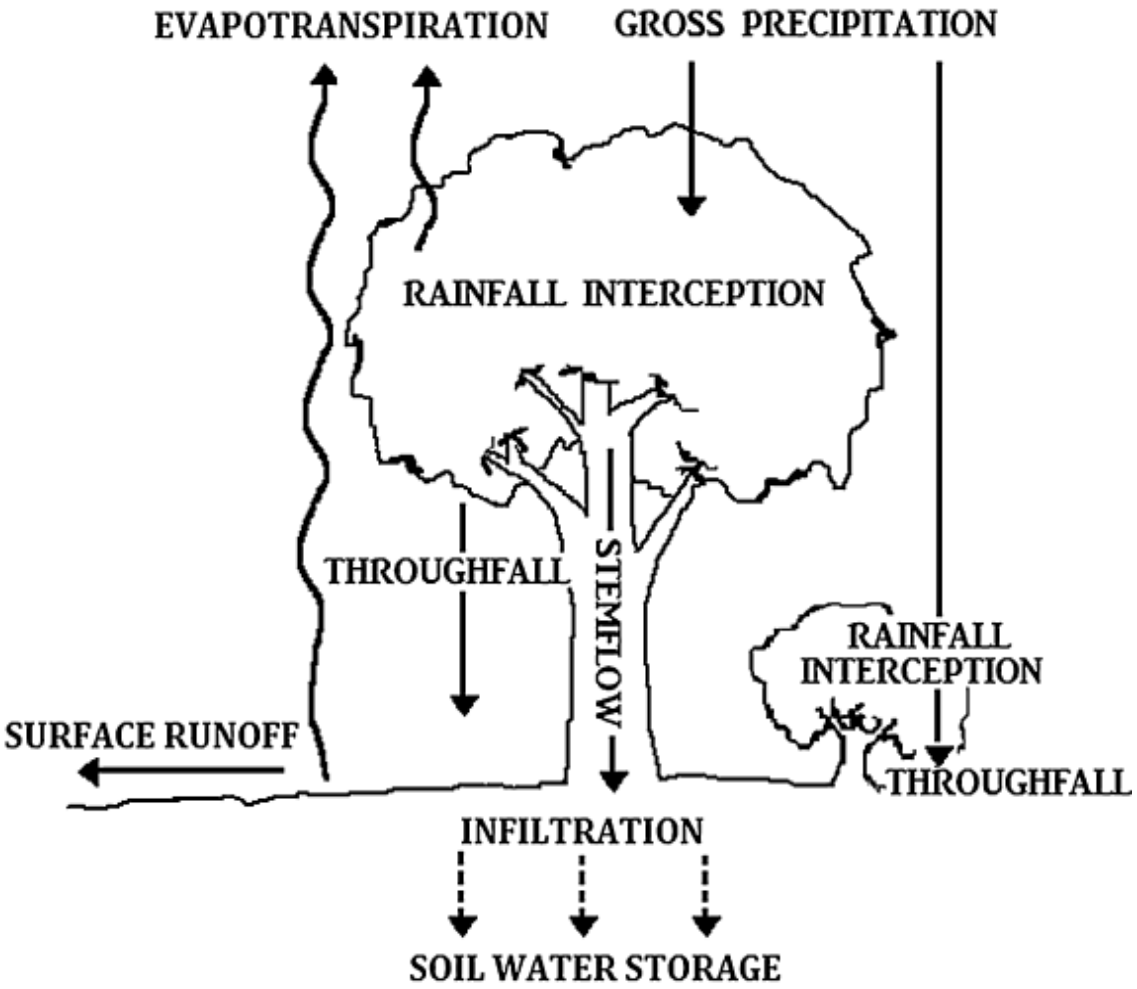

Bioretention Suspended Pavement System
Flow and water quality monitoring equipment
Bald Cypress Tree
Curb cutout allowing stormwater runoff to enter system
Sap Flow Sensor
Suspended Pavement System
Underlying subsoils
Bioretention media


No Flow
Outflow
y = 0.0632x - 1.0993
R² = 0.5651
Dt = 17mm
Outflow Volume (m³)
3.00
2.00
1.00
0.00
0
10
20
30
40
50
60
70
80
Rainfall Depth (mm)

© WENN.com

Urban Trees: Stormwater Benefits

- **Hydrology**
  - Interception
  - Transpiration
  - Infiltration
- **Water Quality**
  - Linked to N and P reduction
  - Limited research



Inkilainen, E. N. M. et al. (2013)

Lit Review (Kuehler et al. 2017)

Species	Reported rainfall retention (%)	Foliage present	Crown area index	Rainfall intensity (mm/hr)	Location	Reference
Citrus	6–9	Yes	–[a]	38–61[b]	Fort Pierce, FL	Li et al. (1997)
Citrus limon	27	Yes	3.0	11–14[b]	San Francisco, CA	Xiao and McPherson (2011)
Eucalyptus nicholii	44	Yes	3.9	14[f]	Melbourne, Australia	Livesley et al. (2014)
Eucalyptus saligna	29	Yes	3.0	14[f]	Melbourne, Australia	Livesley et al. (2014)
Fagus grandifolia	31	Yes	5.5	0.8,1.6[c]	Ghent, Belgium	Staelens et al. (2008)
Fagus grandifolia	10	No	–[a]	0.6,1.4[c]	Ghent, Belgium	Staelens et al. (2008)
Ficus benjamina	60	Yes	–[a]	1.2–20.3	Queretaro City, Mex.	Guevara-Escobar et al. (2007)
Gingko biloba	38	Seasonal	5.2	11–14[b]	San Francisco, CA	Xiao and McPherson (2011)
Liquidambar styraciflua	14	Seasonal	4.7	11–14[b]	San Francisco, CA	Xiao and McPherson (2011)
Pyrus calleryana	15	No	–[a]	1–28	Davis, CA	Xiao et al. (2000)
Pseudotsuga menziesii	49	Yes	–[a]	1.1,13.3[c]	Vancouver, BC	Asadian and Weiler (2009)
Quercus suber	27	Yes	3.4	1–28	Davis, CA	Xiao et al. (2000)
Thuja plicata	61	Yes	–[a]	1.1,13.3[c]	Vancouver, BC	Asadian and Weiler (2009)
Coniferous—summer[e] Coniferous—winter Deciduous—summer Deciduous—winter	81.7 71.4 67.1 45.8	Yes Yes Yes No	[a]	1.2	Vancouver, BC	Asadian (2010)
Variable (67% tree canopy cover)	21[d]20	Seasonal	1.9	32–38[b]	Raleigh, NC	Inkilainen et al. (2013)

Lit Review – What is Lacking?

- Interception for open-grown trees
- Runoff coefficient adjustments
- Scaling local effects to watershed

Methods

- 3 trees per species
  - Red Maple
  - Willow Oak
  - White Pine
- Local Parks
  - Adair (RM)
  - Caswell (WO)
  - Victor Ashe (WP)

Tree Characteristics

	Adair Park (Red Maple)			Victor Ashe Park (White Pine)			Caswell Park (Willow Oak)		
	Tree 1	Tree 2	Tree 3	Tree 1	Tree 2	Tree 3	Tree 1	Tree 2	Tree 3
DBH (in)	9.5	8.8	7.1	10.1	13.8	9.8	7.9	9.1	10.5
Tree Height (ft)	31.3	41.0	41.1	22.3	30.0	27.5	26.2	28.0	33.3
Canopy Cover (s.f.)	804.8	780.2	440.1	532.4	573.1	386.2	236.5	358.0	570.0
Percent Crown Missing	15%-20%	20%-25%	20%-25%	1%-5%	5%-10%	10%-15%	0%	1%-5%	0%

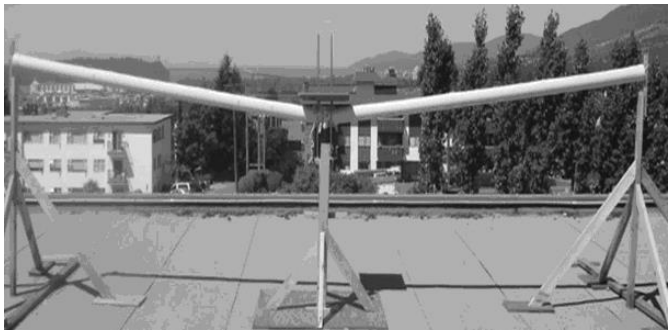
Adair – Red Maple

Victor Ashe – White Pine

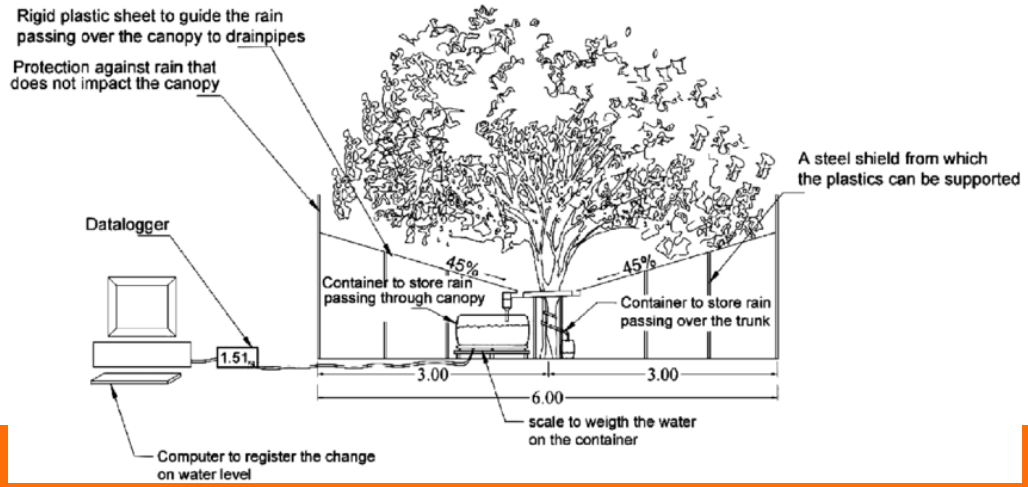
Caswell – Willow Oak

Interception Methods

Venkatraman and Ashwath (2016)



Asadian and Weiler (2009)



Veliz-Chavez et al. (2014)

Stemflow Methods

Venkatraman and Ashwath (2016)

INRA EEF Joint Research Unit Forest Ecology and Ecophysiology
https://appgeodb.nancy.inra.fr/biljou/en/fiche/interception-des-precipitations

Methods

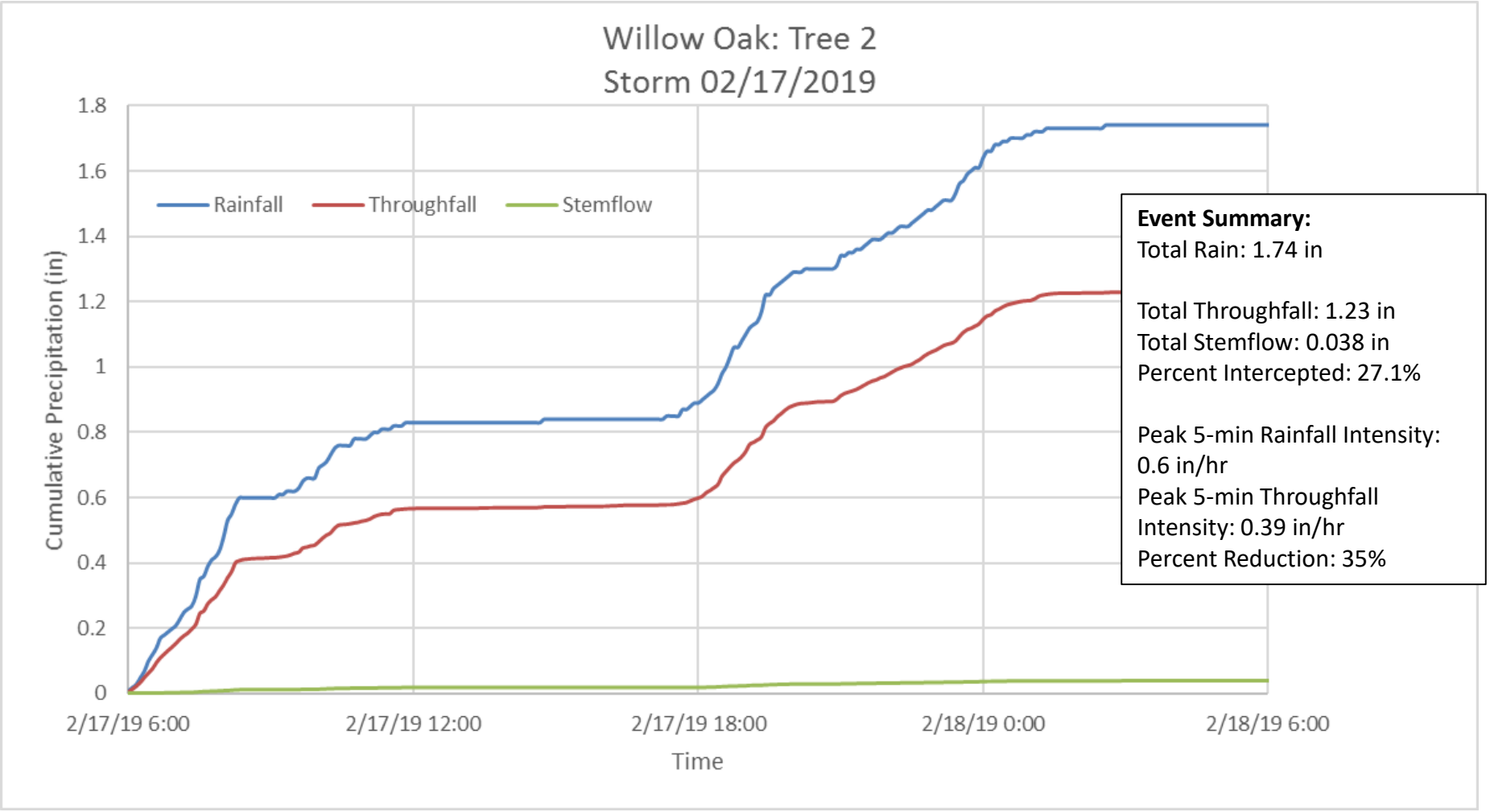
Methods

Methods

Calibration Procedure

Results: Summary of Events

Park Name	Species	Number Of Storms	Mean (Median) Event (in)	Range of Events (in)	Event Duration (hrs)
Adair	Red Maple	108	0.62 (0.40)	0.05 – 4.28	0.17 – 51.3
Caswell	Willow Oak	109	0.54 (0.34)	0.04 – 5.73	0.08 – 61.3
Victor Ashe	White Pine	105	0.49 (0.28)	0.05 – 2.20	0.17 – 38.4



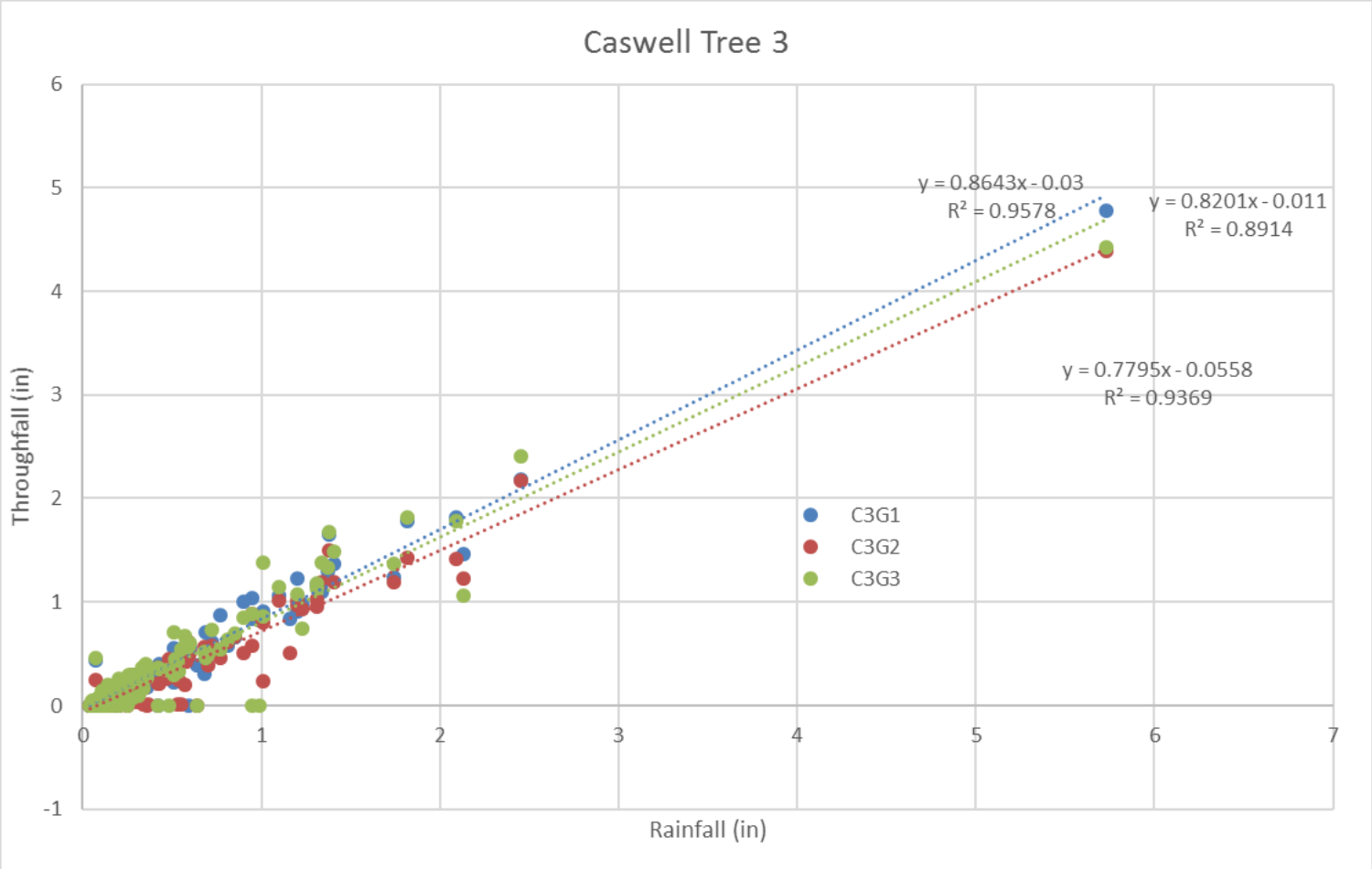
Event Summary:
Total Rain: 1.74 in

Total Throughfall: 1.23 in
Total Stemflow: 0.038 in
Percent Intercepted: 27.1%

Peak 5-min Rainfall Intensity: 0.6 in/hr
Peak 5-min Throughfall Intensity: 0.39 in/hr
Percent Reduction: 35%

Urban Field Work

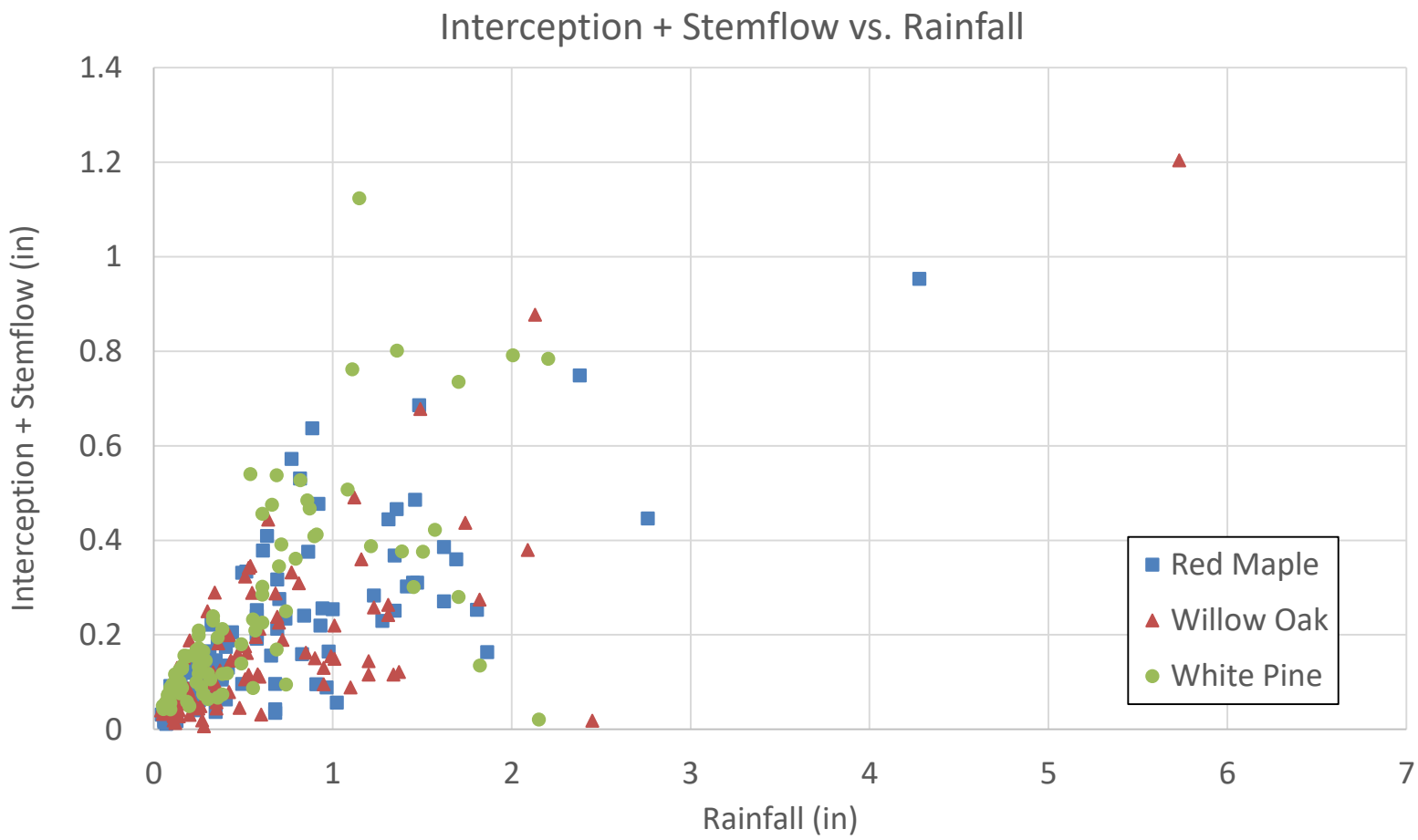
Outlier Removal



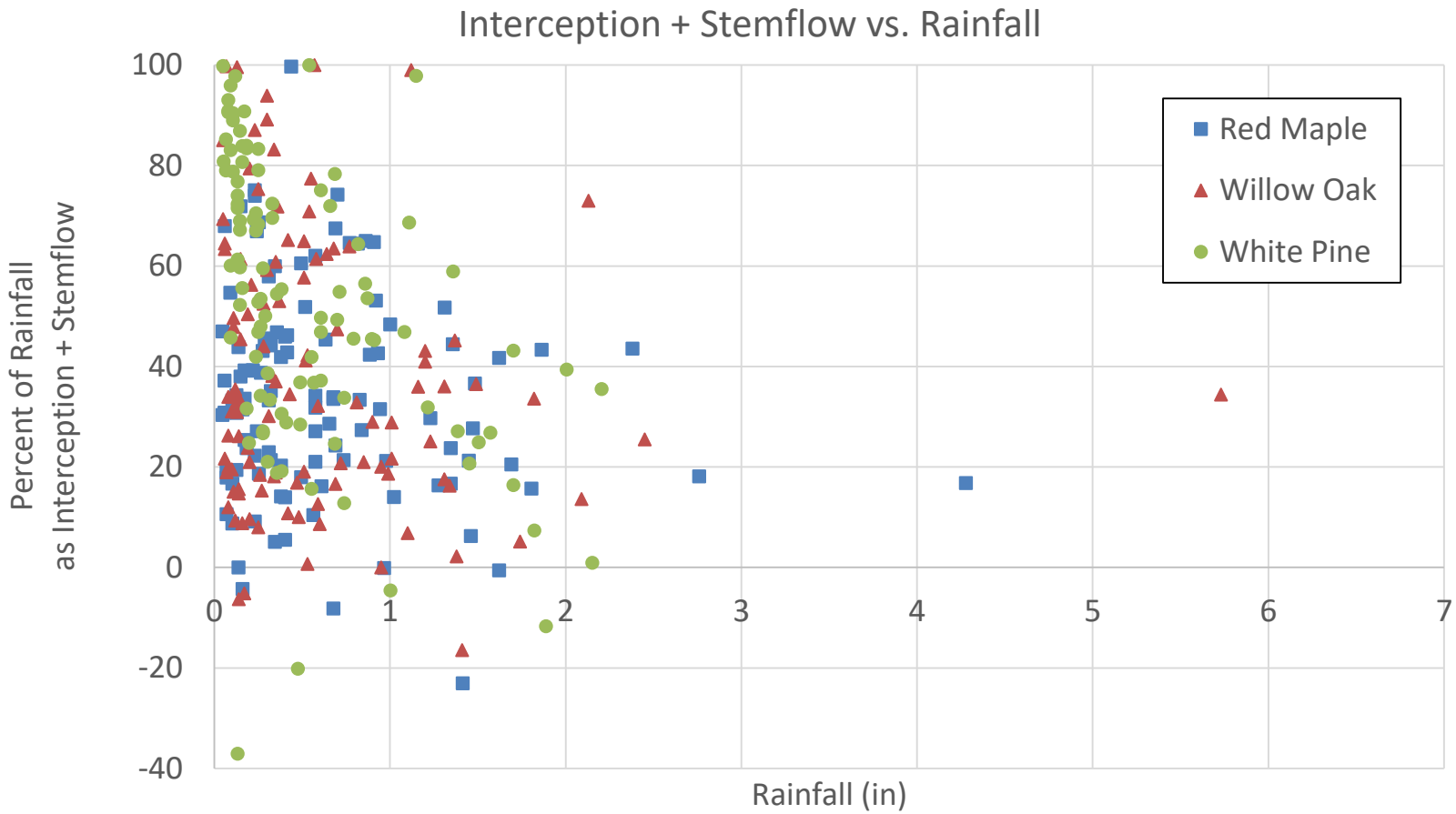
Rainfall Partitioning

Location	Species	Mean (Median) Interception (in)	Mean Stemflow (in)	Total Interception and Stemflow (%)
Adair	Red Maple	0.18 (0.12)	0.02	29
Caswell	Willow Oak	0.14 (0.10)	0.01	28.5
Victor Ashe	White Pine	0.20 (0.12)	0.01	43

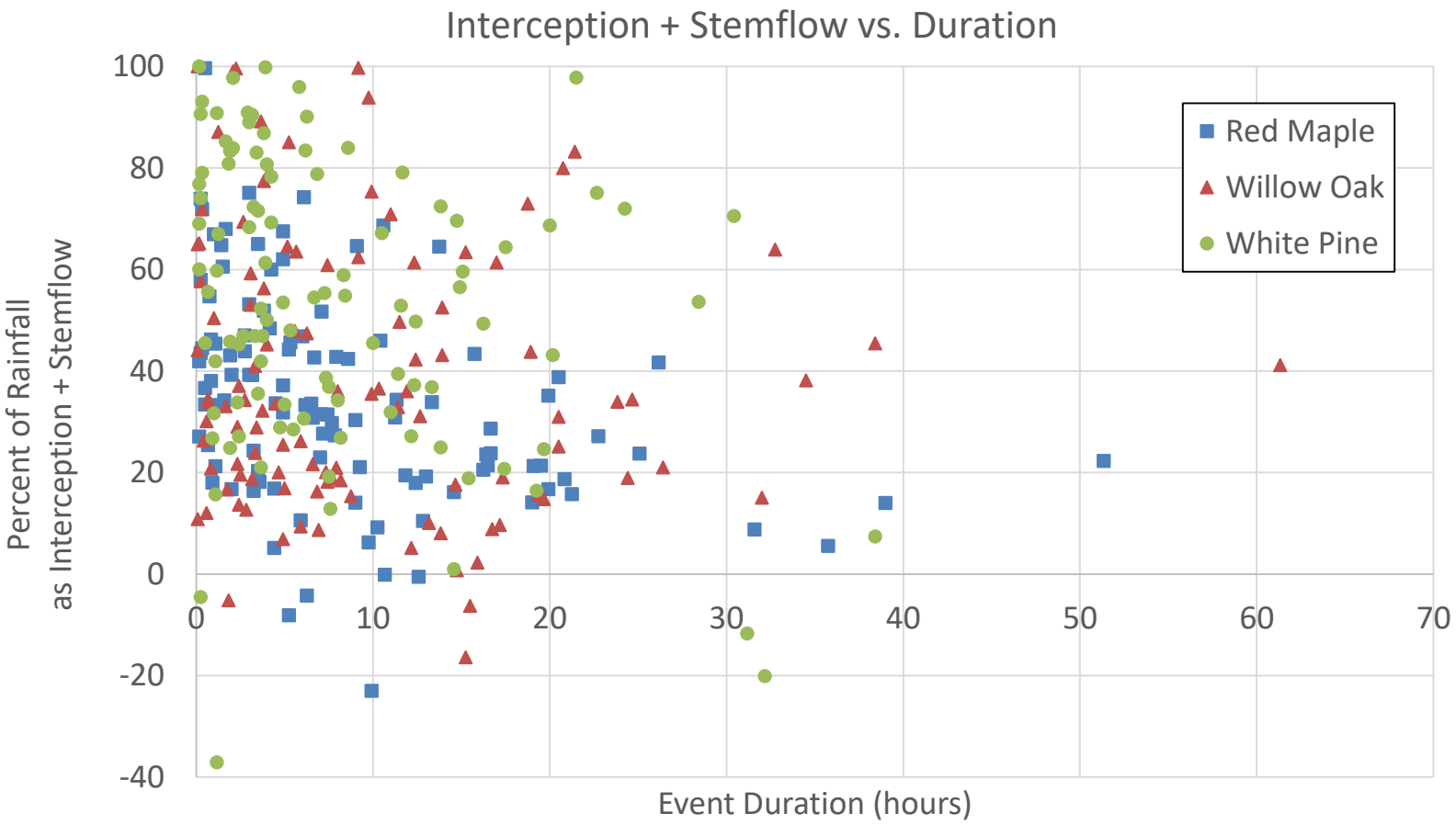
Rainfall vs. Interception / Stemflow



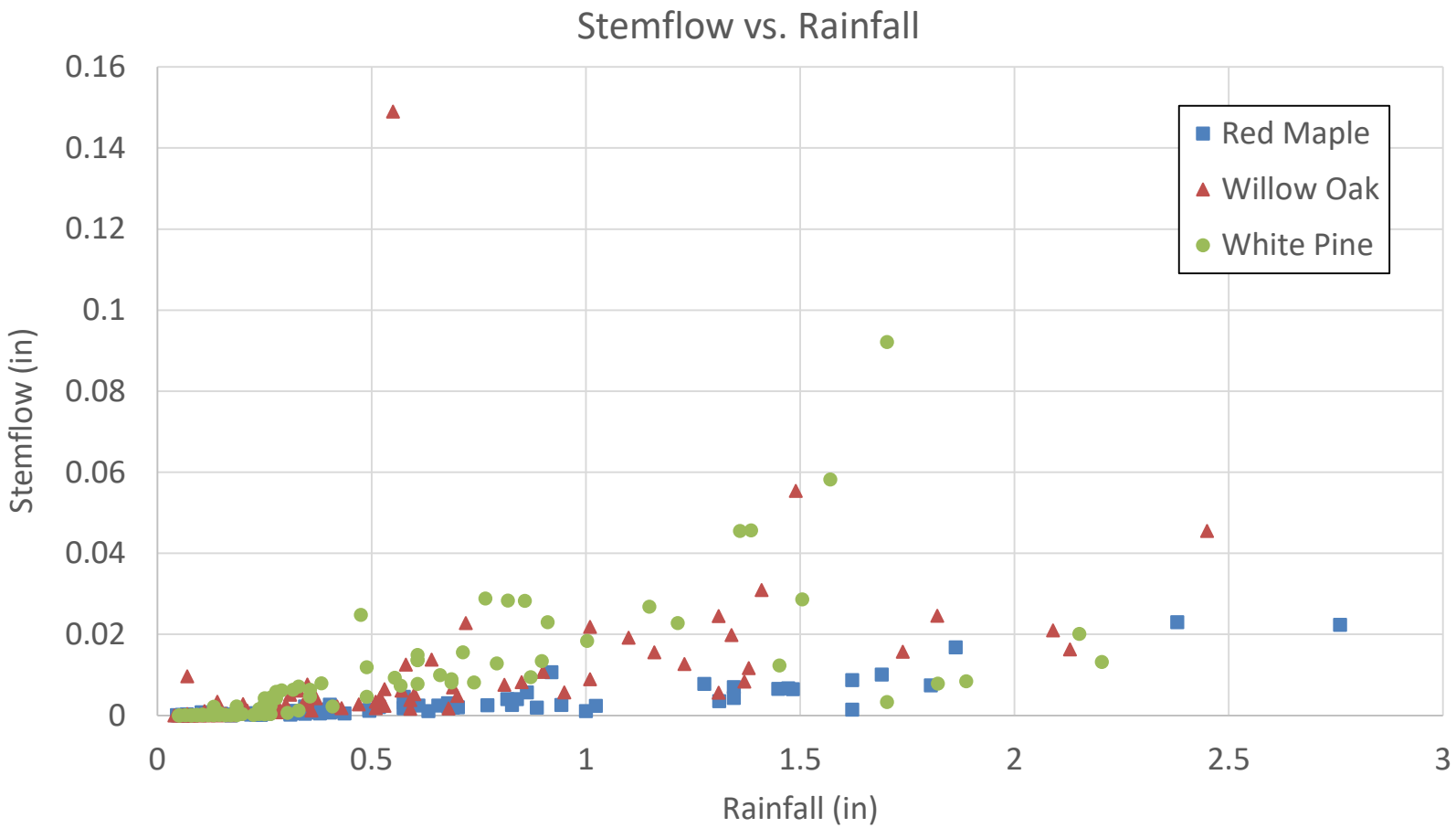
Rainfall vs. Interception / Stemflow



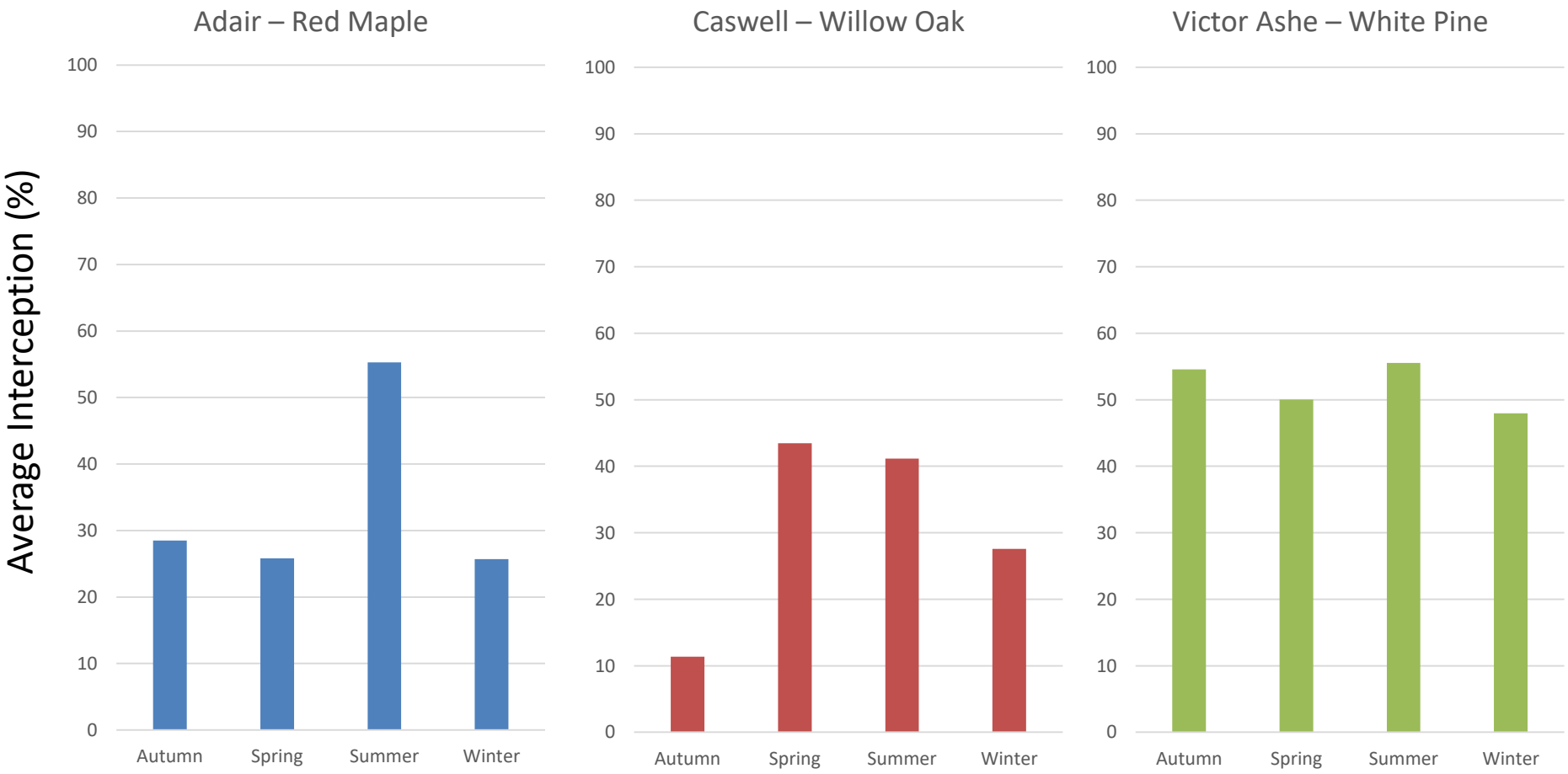
Duration vs. Interception / Stemflow



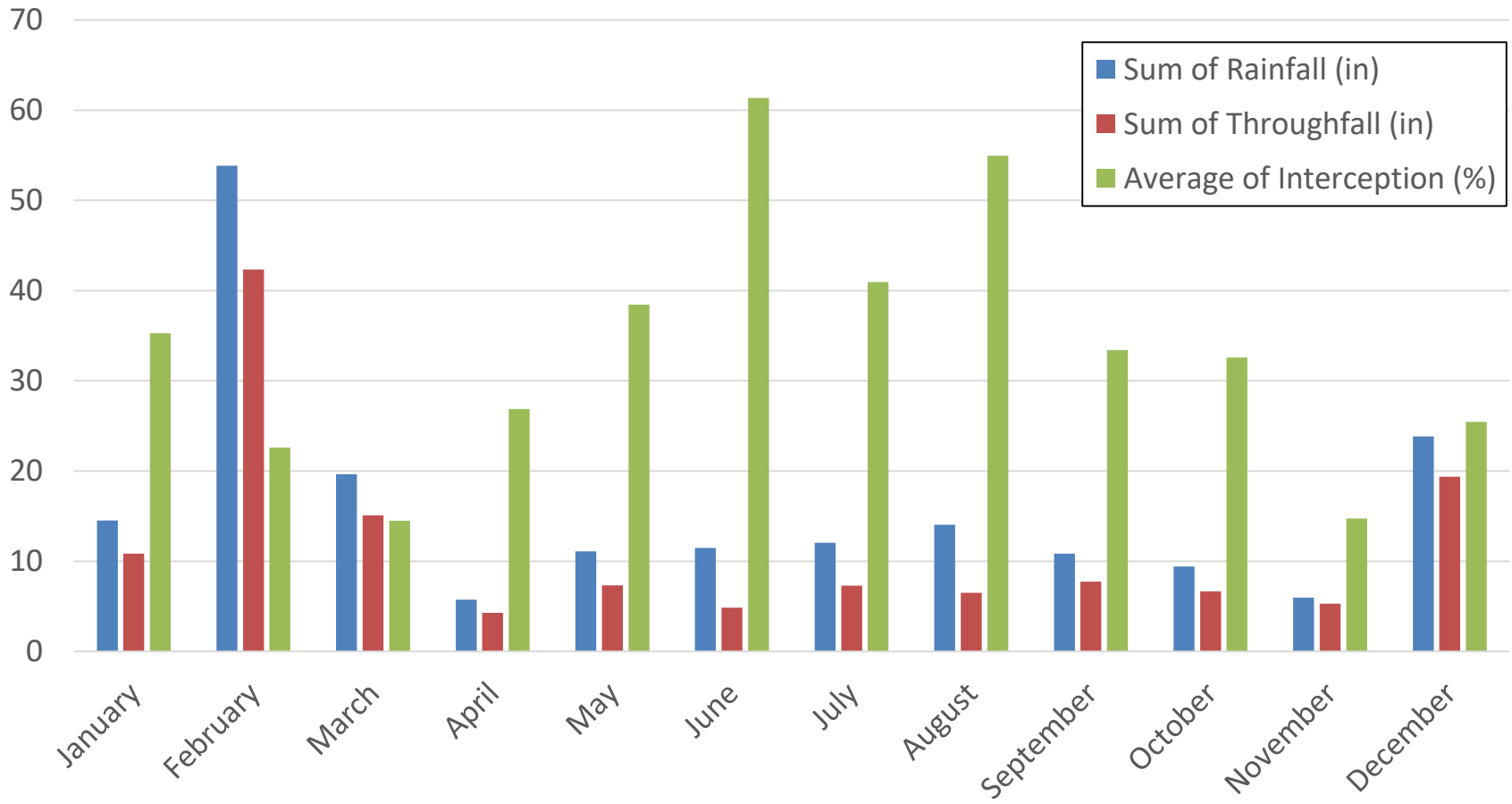
Rainfall vs. Stemflow



Seasonality



Seasonality (Adair – Red Maple)



Discussion

- Site scale vs. watershed scale
  - May be useful intervention for communities
- Stormwater Management?
    - Peak flow reduction
    - Volume retention
    - Pollutant removal?
    - Infiltration enhancement
- Critical to understanding how trees may be credited

Design Implications

- Credit?
  - Chesapeake Bay
  - Expert Panel: Urban Tree Canopy Expansion
- Center for Watershed Protection
  - Making Urban Trees Count
- Kansas State University (WERF)

Recommendations of the Expert Panel to Define BMP Effectiveness for Urban Tree Canopy Expansion

Karen Cappiella, Sally Claggett, Keith Cline, Susan Day, Michael Galvin, Peter MacDonagh, Jessica Sanders, Thomas Whitlow, Qingfu Xiao

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- Work funded by the United States Forest Service (USFS)

Questions?

hathaway.utk.edu

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